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THESIS

1973 VARIATIONS OF HURRICANE HEAT POTENTIAL
IN THE PHILIPPINE SEA AND THE GULF OF MEXICO

by

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1973 Variations of Hurricane Heat Potential in the Philippine Sea and the Gulf of Mexico

by

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ABSTRACT

The 1973 summer growth of hurricane heat potential (HHP) and its relation to tropical cyclones was studied in the Philippine Sea and the Gulf of Mexico on a monthly basis. BT information was processed through the Fleet Numerical Weather Central CDC 6500 computer to output maps of HHP, which were hand contoured. Inadequate data coverage and questionable BT observations resulted in monthly maps of varying validity and areal extent.

HHP values peaked near 35,000 cal/cm^2-column in the Gulf of Mexico and 40,000 cal/cm^2-column in the Philippine Sea in the months of August and September, the months of highest tropical storm activity.

In the Gulf of Mexico the 1973 HHP maximum-minimum values compared well with the HHP values obtained in August 1965-1968 by Leipper and Volgenau [1972].

HHP values from the Philippine Sea were in close agreement with the atlas values computed by Heffernan [1972]. Maximum values for 1973 were slightly (5000 cal/cm^2) higher.

Some evidence was found correlating rises in HHP with increases in typhoon maximum wind speed.

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I. INTRODUCTION

A. LITERATURE REVIEW

The importance of the ocean regime influence on tropical storm activity has long been suspected, but the exact nature of the interrelationships between the sea and tropical storms remains largely unknown.

As early as 26 years ago Palmen [1948] stated that the sea surface temperature must exceed 26°C in order for a hurricane to develop. Direct relationships between the sea surface temperature field and a hurricane's track and intensity were investigated. Fisher [1958] published evidence that hurricane tracks are biased towards zones of warmest waters, and that the storms weaken in passing over cool water areas.

Perlroth [1962,1967,1968] also supported the conclusion that hurricanes tend to intensify over warm waters and weaken over cool waters. However he strongly emphasized that the transfer of energy between the ocean and a tropical cyclone was dependent upon the thermal structure of the entire surface layers and not just upon the sea surface temperature.

Whitaker [1967] first utilized the concept of hurricane heat potential (HHP), defining it as the heat content of the water column above 26°C.

Hurricane heat potential is computed through the equation: $Q = \rho C_p \Delta T \Delta Z$, where:

ρ = density (gm/cm^3);

C_P = specific heat at constant pressure (cal/gm/degree);

ΔT = temperature difference, (°C) calculated as the average amount by which the water temperature value exceeds 26°C for a unit depth increment

ΔZ = depth increment (cm).

While actually a sensible heat measurement (heat available in a cm^2-column of water), HHP is proportional to the area between the 26°C isotherm and a temperature sounding or profile drawn on temperature-depth coordinates. HHP is not necessarily proportional to sea surface temperature alone, but it is determined by the detailed thermal structure. Figure (1) from Jensen [1970] illustrates how two locations can have identical surface temperatures, but may differ markedly in HHP.

Many studies which seek to establish a relationship between sea surface temperature and hurricanes are pertinent, and it is likely that both parameters, sea surface temperature and HHP, significantly affect hurricane behavior.

Sea surface temperature acts as an initial influence on a hurricane. Energy transfer from the sea to a storm which takes place by evaporation and conduction is related to the sea-air temperature difference both as a direct influence and as an indirect influence through boundary stability. Thus the value of sea surface temperature is very important, and the initial value felt by a hurricane more or less determines the initial energy input from the sea surface.

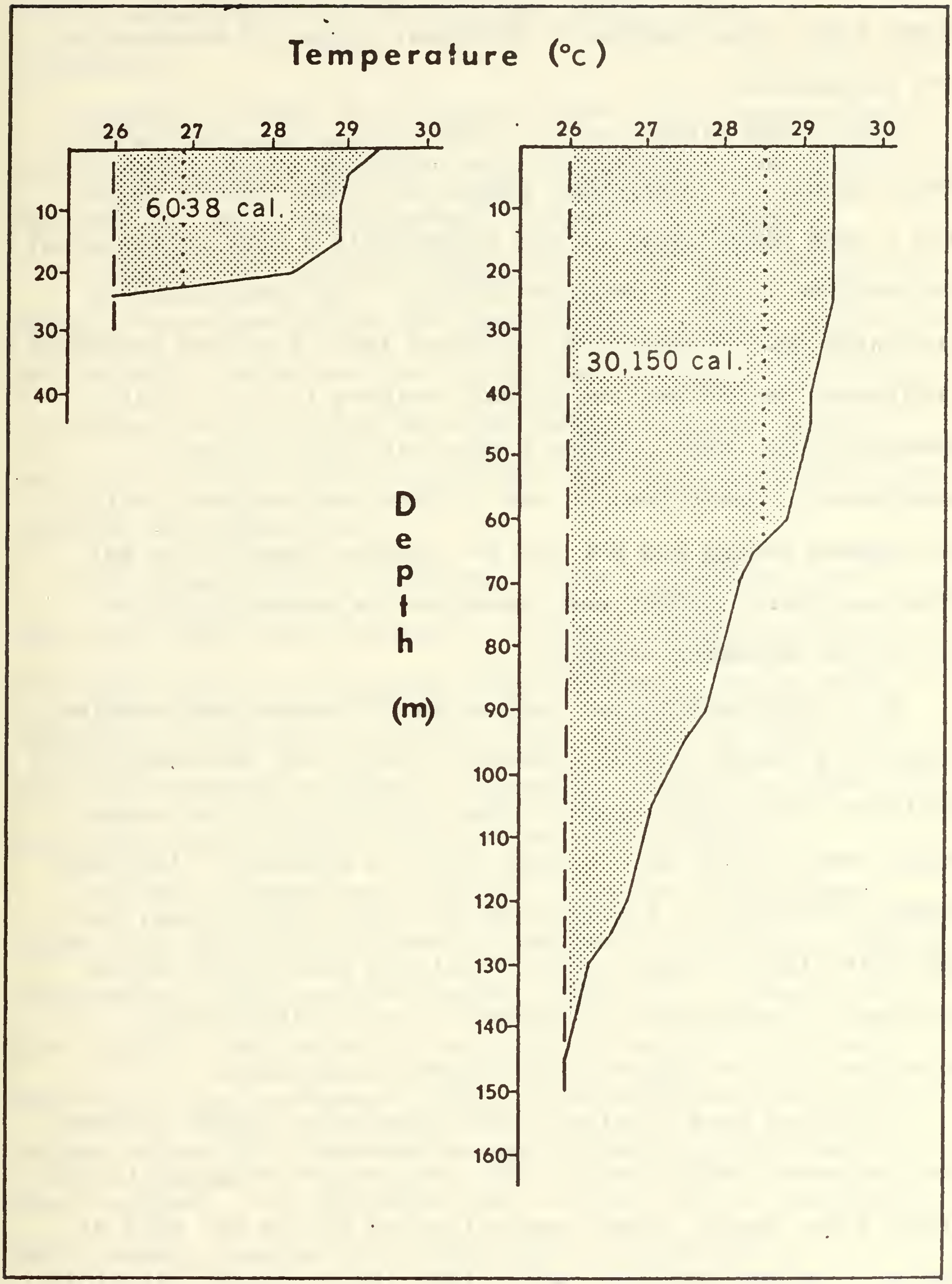

Figure 1. Schematic Comparison of Two Vertical Temperature Distributions [Jensen 1970]

However, the sea surface temperature may change as the ocean loses heat, thus leading to different values of evaporation and conduction.

For a thin mixed layer the sea surface temperature will drop rapidly as a hurricane passes over the region, while for a deep mixed layer it may change only a very small amount in response to the same loss of heat. The temperature of the water and the depth of the mixed layer are both important influences on HHP and are closely related to it. It is generally true that regions having high HHP will not experience a rapid drop in sea surface temperatures, while in regions having low HHP the sea surface temperature may drop much more rapidly and therefore the energy input to the storm decreases rapidly.

As a long term energy indicator, HHP shows much promise. Studies by Malkus [1962], Leipper [1967], and Whitaker [1967] indicate that a passing hurricane extracts from the ocean about 4000 cal/cm^2/day. Since HHP is a measure of the heat energy available to a hurricane from the water column, and the approximate energy exchange rate is known, HHP can be utilized to ascertain the number of days a stationary hurricane can be supported by a given ocean area.

Utilizing data obtained from consecutive August cruises for the years 1965 through 1968, Leipper and Volgenau [1972] studied the annual August variations of HHP in the Gulf of Mexico. Values obtained ranged from 700 to 31,600 calories/cm^2-column. Tongues of high and low HHP were discovered.

These varied yearly as to location, extent, and intensity.

Volgenau [1970], in a related paper, had discussed the possibility of a correlation existing between heat availability and the intensity and movement of ensuing hurricanes.

Leipper and Volgenau [1972] plotted the path of Hurricane Betsy on the appropriate HHP field, and a possible connection was evident. Betsy was one of the most powerful hurricanes of recent years and this may have been related at least in part to the fact that Betsy passed over the area of the Gulf showing the highest HHP.

The climatological variation in HHP was addressed in 1972, when Heffernan produced a monthly mean HHP atlas for the North Atlantic and North Pacific Oceans. His results indicated the presence of deep, warm centers of water with high HHP existing in areas of hurricane formation during the months of most frequent tropical storm development.

The HHP maximums were reached in August in Heffernan's atlas, and this corresponded to the month of maximum typhoon occurrence in the Western Pacific (Figure 2). However, in the Atlantic, September is the month of maximum hurricane activity [Sugg and Hebert 1969]. Here Heffernan's atlas showed August and September as the months when HHP maximums were reached. The Caribbean Sea, a prime area of hurricane development, reached its highest HHP in September.

Evidence suggests that HHP may be useful in revealing some of the effects of the ocean on tropical storms.

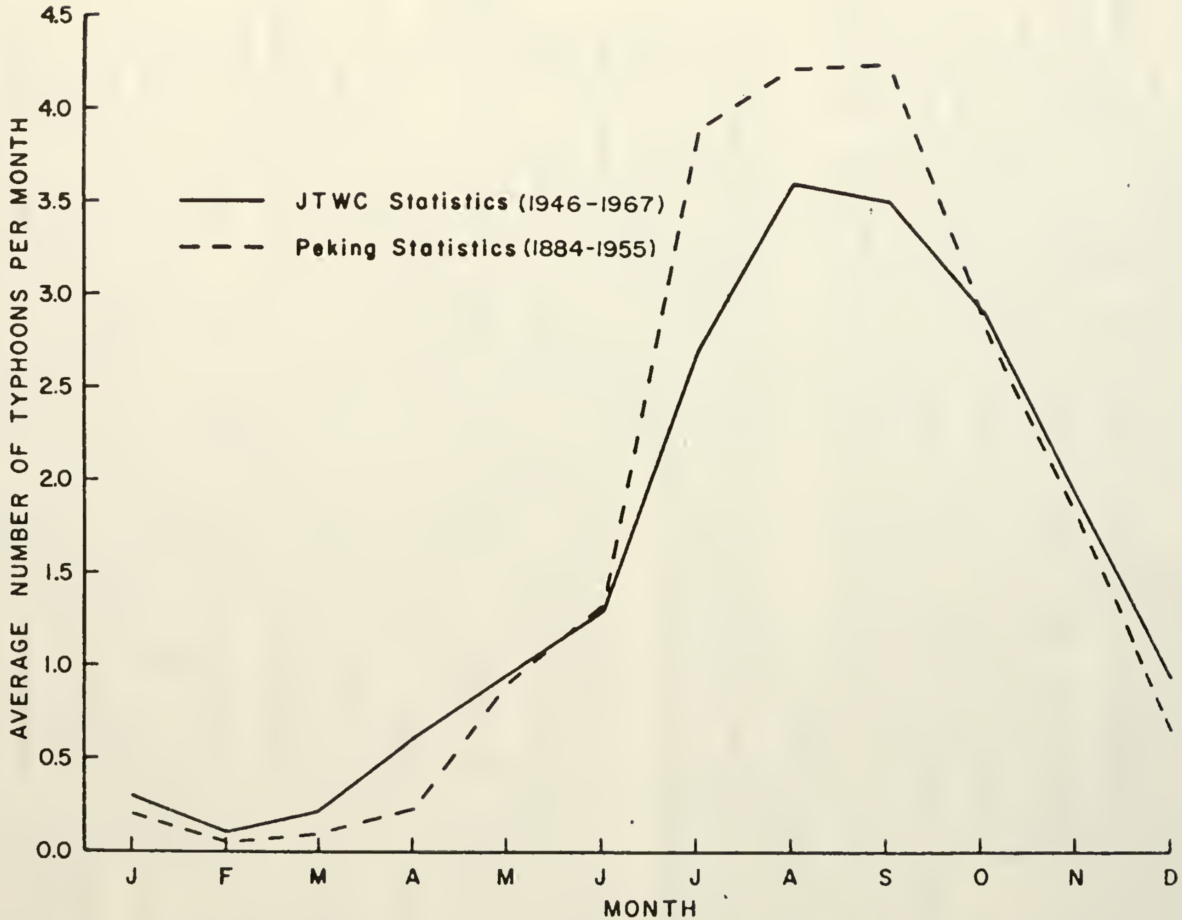

Figure 2. Monthly Variation in the Average Number of Typhoons. (The Peking Statistics Probably Include a Number of Tropical Cyclones Which Were Not of Typhoon Intensity.) [Gray 1970]

B. THESIS OBJECTIVES

1. To study the large-scale development and growth of the HHP in the Gulf of Mexico and the Philippine Sea during the 1973 hurricane season, and to compare the mean values of HHP as found by Heffernan to the 1973 potentials.

2. To correlate the deviation of the 1973 HHP from the average potential with the deviation of the 1973 storm activity from the average storm activity. To check if higher or lower HHPs appeared to be associated with a higher or lower frequency of storms.

3. To investigate the possible effects of HHP on individual storms and conversely, to investigate the effects of individual storms on HHP. To compare the tracks of individual storms to the HHP fields, to see if the storm track might have been influenced by the areas of highest HHP. To study intensities of storms to determine how the HHP associated with them differed from the average.

4. To test a method of utilizing operational bathythermographs (BTs) for research, in particular to determine the contribution of classified BTs to the total data base.

II. APPROACH

A. AREAS AND EXPECTED RESULTS

Maps of HHP for ten-day intervals in the months of May-September, 1973 were constructed from bathythermograph data in the Philippine Sea and Gulf of Mexico. According to Heffernan's atlas of average conditions [1972], this time sequence of charts should have shown a build-up in the HHP as the 1973 hurricane season progressed, with maximum heat potentials occurring in the months of greatest storm activity, and declining as the tropical storm season waned.

These 1973 HHP values in the Gulf of Mexico and the Philippine Sea were compared to the monthly means for the same areas as computed by Heffernan [1972]. The deviation of the 1973 HHP from the monthly mean potentials was studied. August 1973 HHP fields in the Gulf of Mexico were compared to the Ocean Heat Potential maps of Leipper and Volgenau [1972]. The degree of correspondence between hurricane activity and heat potential was sought.

Possible relations between the HHP fields and individual storms were scrutinized. Large areas were studied to see if the passage of individual storms caused decreases in oceanic heat content, as past studies indicated might be expected.

B. DATA USE

The 1973 data base was tested to determine if a sufficient number of BT observations and adequate area coverages

were available to describe accurately the 1973 HHP fields. The benefits of the inclusion of classified BT reports were studied.

The possibilities of utilizing real time data from Fleet Numerical Weather Facility, Monterey, California were considered, especially as related to synoptic descriptions of the heat potential fields.

Computer processing and plotting by location of BT data to obtain maps of HHP data points was set up on the FNWC CDC 6500 computer. The validity of the individual HHP computations was carefully checked before the computations were entered on each map.

C. OTHER HHP-RELATED INVESTIGATIONS

An ocean sampling program for the Philippine Sea initiated in May of 1972 was compared to the BT observations taken in July and August of 1973, to determine if the goals of the program were being carried out.

Another study attempted to find a correlation between the HHP fields in the Gulf of Mexico as defined by Volgenau [1970] and the tropical storm activity in the related years.

III. PRESENTATION OF DATA

A. SOURCES

1. General

The bathythermograph data used in this thesis was obtained from the Climatology Section of the Fleet Numerical Weather Central, Monterey, California.

Sea temperature profiles were taken by ships and aircraft of the United States Navy, research ships, and merchant vessels. Mechanical, expendable and air-expendable BTs were utilized.

2. Addition of Classified Data

The Philippine Sea in 1973 was in an area of extensive U.S. Navy operations and the completeness of the data fields was greatly enhanced with the addition of confidential BT recordings. Table (1) shows that the data base was increased by 126% in the Philippine Sea during periods when confidential BTs were available.

The actual benefit resulting from the inclusion of the confidential reports was less than that indicated because often a confidential and an unclassified report were taken at the same position and at the same time. Sometimes numbers of confidential reports were grouped closely together, further limiting their individual value. Finally, of the BTs which seemed erroneous, most of them were confidential.

Table 1. Data Field Expansion by Including Confidential Reports

PHILIPPINE SEA

Period	Conf Rpt (number)	Other Rpt (number)	Data Increase (%)
11-20 June	171	19	900
21-30 June	143	28	511
1-10 July	3	48	6
11-20 July	16	34	47
21-31 July	22	61	36
1-10 Aug.	26	36	72
11-20 Aug.	32	21	152
21-31 Aug.	23	28	82
1-10 Sept.	18	52	35
11-20 Sept.	5	15	33
21-30 Sept.	25	43	58
	484	385	126%

GULF OF MEXICO

Period	Conf Rpt (number)	Other Rpt (number)	Data Increase (%)
July	0	23	0
Aug.	8	88	9
Sept.	5	5	125
	13	115	11%

While the inclusion of confidential reports aided in the Gulf of Mexico analyses, the role of classified data here was of much less importance than in the Philippine Sea.

Deficiencies included, the incorporation of classified BTs in the data fields proved to be a worthwhile action.

The initial computer plots mixed the HHP points computed from classified BTs with the HHP points computed from unclassified BTs. Locations of individual HHP positions were completely disassociated from any specific vessel or time of observation. The first map drawn included these HHP value points, but the smoothed maps show only contour lines and no single point values and are therefore unclassified.

3. Storm Track and Intensity Data

Hurricane best track and wind speed information was obtained from Mr. S. Rinard, Meteorology Department, U.S. Naval Postgraduate School. He received his 1973 track data from the National Climatic Center, Nashville, North Carolina.

Mr. S. Brand of the Environmental Prediction Research Facility, Monterey, California provided the typhoon best tracks for July and August from data supplied by the Fleet Weather Central, Guam. September typhoon information was obtained directly from Fleet Weather Central, Guam.

B. PROCESSING

1. Computer Processing

BT data for the periods and areas studied were obtained from the FNWC Climatology Division in the form

of 4-d format punch cards. The cards were manually divided into the geographical areas and time periods of interest. Cards containing only surface temperature information were eliminated at this time, since the computation for HHP requires subsurface profiles. Data cards on which the temperature did not go below 78.8°F (26°C) were also discarded, since in the computer program this precluded the determination of heat potential.

Each set of data cards was then processed through the FNWC CDC 6500 computer, utilizing two programs developed by Mr. Kevin Rabe of the Environmental Prediction Research Facility, Monterey, California. A flow chart, showing subroutines involved, is included as Figure 37.

The first program (Appendix A) computed the value of the hurricane heat potential and stored this value and its related geographic position on tape. Concurrently a printout for each individual station was made. Of great value in performing later checks, this printout indicated the vessel taking the BT, the time, the security classification and the position. The depth and temperature at each subsurface point was recorded. Heat potential in hundreds of calories/cm^2-column and the depth of the 22°C isotherm in meters were given. A plot of the temperature vs. depth profile was obtained (Figure 38) on a non-linear depth scale.

The second program extracted the HHP value from the tape and utilized the FNWC "Variset" Program to produce a

computer plot of the HHP printed beside each location where a BT observation had been taken.

The computer-plotted HHP values were then transferred to tracing paper to facilitate later comparison of HHP fields, and the HHP contours were faired in.

2. HHP Value Checks

Each HHP value was compared carefully with the surrounding HHP values. If the HHP value was radically different from those in the immediate vicinity, checks were made to determine the validity of the anomaly.

The fact that mechanical BT (MBT) data could not be distinguished from expendable (XBT) and air-expendable (AXBT) BT data hampered the checking of the correctness of the observation. An error existing in a MBT may appear in many observations, whereas XBT and AXBT observations each should be independent. If a ship using a MBT shows consistently higher BT readings, it may be due to an uncalibrated bathythermograph.

Instances occurred where two ships would take BTs from the same position and at the same time, yet the initial surface temperature would differ by 1.5 to 2°C. This in turn resulted in widely differing heat potentials.

The correct computation of HHP was extremely sensitive to the BT profile, and any temperature error in the BT magnified itself, becoming a gross error in the heat potential. For example, if a sea surface temperature were in error by 1°, this same error could have been present at

all depths on the BT trace, as in the case of a mechanical BT out of calibration. If the 26°C isotherm extended down to 150m, the error in the HHP value in this case would have been 15,000 cal/cm^2-column. Since the total range in HHP varied roughly between 0 and 40,000, the importance of such errors is apparent.

One method of checking BT observations for reliability would be to have a large number of BTs in a small area to check against each other. Another independent check to ensure initial accuracy of the sea surface temperature of a BT would be to cross-check with a bucket thermometer observation.

In checking the HHP values obtained, each BT was first checked internally. The printout of the BT was examined to determine if any apparent irregularities in the temperature-depth profile were present.

The baseline temperature (surface temperature) was checked against the maxima as defined in SP-123 [1969] and H.O. 700 [1967]. When surface temperatures were discovered to fall outside of the maximum-minimum limits, they were not discarded, but were more closely scrutinized. H.O. 700 treats only extremes falling within the 95th percentile, and SP-123 states, concerning the Philippine Sea, "...large amounts of extremely warm water west of 160°E and south of 20°N are highly variable, both seasonally and annually, and are in need of more intense study."

High HHP values in the Philippine Sea were compared also to the means as computed by Heffernan [1972]. This illustrated the large amounts by which Heffernan's Philippine Sea highest means were exceeded by several 1973 BTs. While it is recognized that means are always lower than the high extreme, and that the mean for one individual year may differ markedly from the mean computed for an extended period of time, several differences in excess of 20,000 cal/cm^2 seemed excessive.

Comparison of BTs with others in the immediate vicinity proved to be the most satisfactory method of eliminating unreliable reports.

Figure (3) shows three BTs taken off the southwest of Cuba by the same vessel, over a three-hour period. The report at 1000 hours had an extremely high HHP, but the surface temperatures of all three BTs were in close agreement. However at 49 meters, the 1000 report had an unexplained increase in temperature of nearly 5°C. This deviation resulted in the remainder of the trace, while closely following the other two readings in shape, being approximately 3°C warmer. Comparison with surrounding BTs led to the conclusion that the 1000 BT was in error.

Figure (4) illustrates a common source of error when abnormally low values of HHP were indicated. Two reports, Ship A and Ship B, were taken at the same location, eight minutes apart. Ship A indicated a HHP of only 3,700 cal/cm^2-column while Ship B had a HHP of 40,600 cal/cm^2-column. The

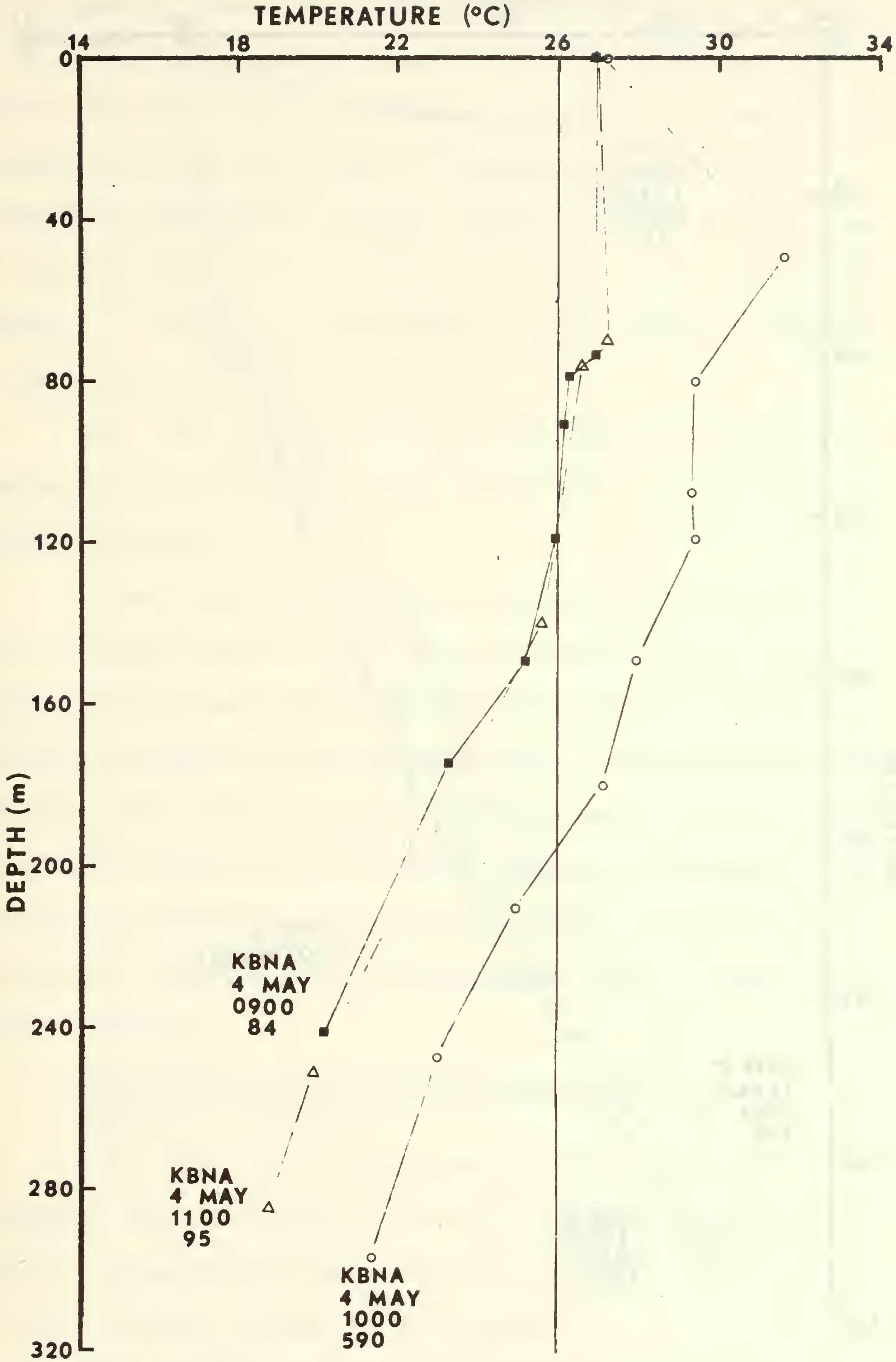

Figure 3. Hourly BT Profiles and HHPs (10^2 cal/cm^2) Illustrating Large Deviations Caused by Differing BTs.

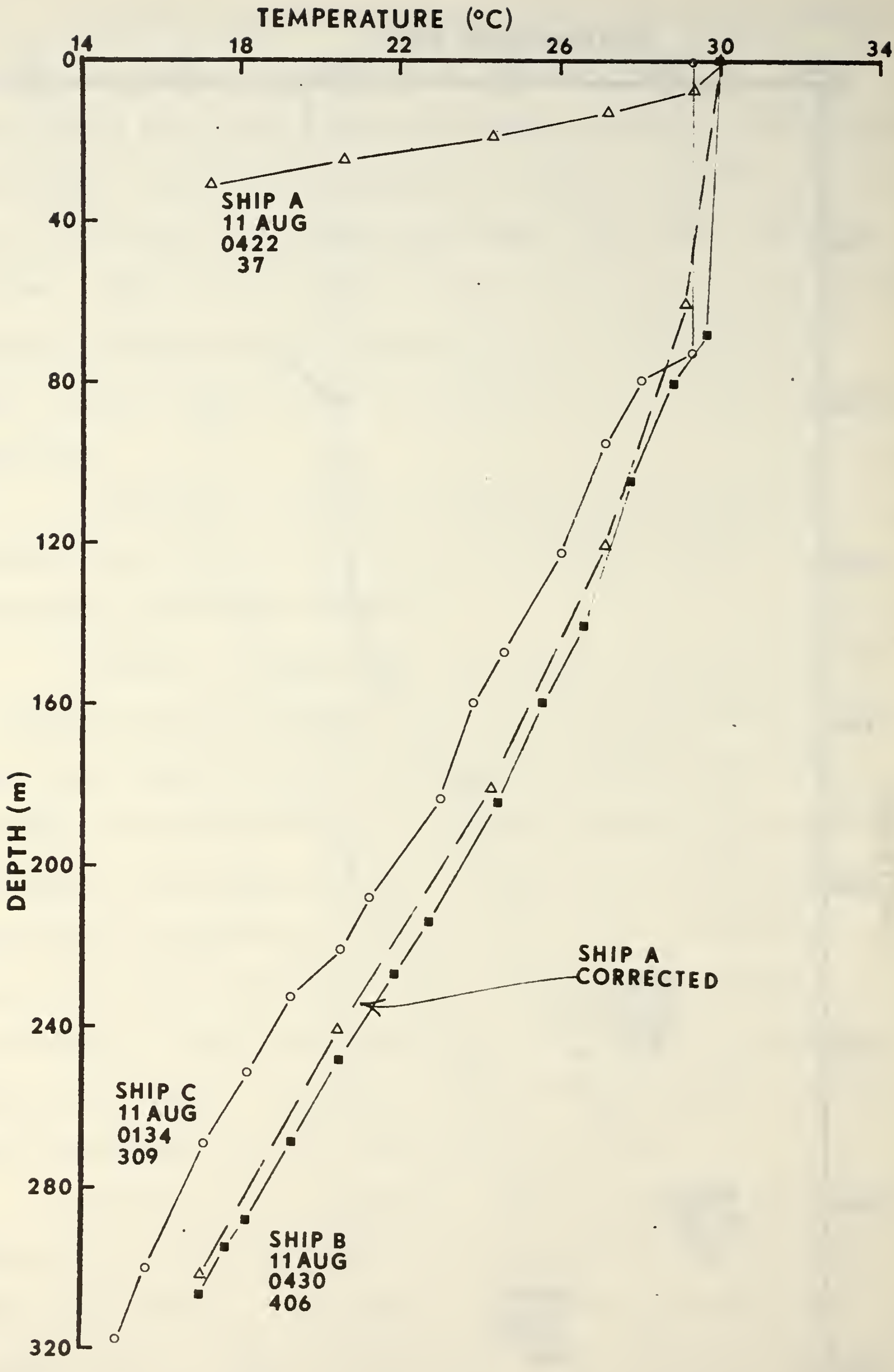

Figure 4. Philippine Sea BT Profiles Illustrating Source of Low HHP Errors.

Ship C report, taken three hours prior and within 25 miles of the first two reports, showed a HHP of 30,900 cal/cm^2-column. When the depth increments on the Ship A report were increased tenfold, the Ship A temperature-depth profile showed good agreement with the other two BTs. The conclusion was that the last digit of Ship A's report had been omitted somewhere in the data transmission or processing. This was not an uncommon type of error.

The 11-20 August period in the Philippine Sea, for example, had the greatest number of these mis-labelled reports, nineteen.

If an anomalous reading could not be eliminated after a logical analysis, it was included in the contour fields. This caused many extreme value, small area irregularities to appear in the ten-day maps. When these appeared, several consecutive ten-day period maps were checked against each other to see if the anomalies showed persistence. The persistence checks were severely hampered by the lack of consecutive readings from the same positions at succeeding ten-day intervals.

3. Map Production for the Philippine Sea and Gulf of Mexico

Using the computer programs, HHP maps of the Philippine Sea were made at ten-day intervals beginning on 1 May and extending through the major portion of the 1973 hurricane season, ending on 30 September.

Lack of observations was an acute problem in the Gulf of Mexico. The amount of data available fluctuated widely and was dependent largely upon individual scientific ship cruises.

Because of the shortages of BT observations at varying times, the original intention to produce ten-day interval maps in the Gulf of Mexico had to be revised. Ten-day trends were combined to form monthly maps. Even at monthly intervals, the BT information available at certain times in the Gulf was a restrictive factor in showing the monthly HHP changes. In particular, the months of July and September had a minimal amount of BT data available.

C. PROJECT OSTROC

A program for ocean sampling in the Philippine Sea was prepared 2 May, 1972, by the U.S. Naval Postgraduate School's Departments of Oceanography and Meteorology for distribution through the ONR fleet coordinator in Pasadena, California (Appendix B).

The purpose of Project OSTroC (the Oceans and Severe Tropical Cyclones) was to intensify and coordinate the collection efforts for obtaining significant bathythermograph data from the Philippine Sea during the peak typhoon months, June through December. A grid collection network was proposed, which included the establishment of lines of BTs perpendicular to typhoon tracks. It was requested that these lines of observations be made just prior to and

immediately after the passage of a storm through the area, in order to give a timely picture of pre-storm and post-storm ocean conditions.

Figures (5) and (6) are plots of BT data points, shown as squares, taken during July and August, 1973. Shown as circles are desired OSTroC sampling positions. Examination of BT data obtained, while showing adequate coverage of the Philippine Sea, particularly above 10°N, indicated that little systematic data-taking had been performed as outlined in the Project OSTroC letter. Conclusively, there were no perpendicular BT lines laid in conjunction with typhoon tracks.

The primary purpose of Figures (5) and (6) is to show to what extent the OSTroC data collection points had been sampled. Secondarily the figures give a picture of the monthly BT coverage of the area in 1973.

While not conforming to Project OSTroC guidelines, the BT data collected during the months of May through September, 1973 did give sufficient coverage of the Philippine Sea to show the summer trend in the heat potential fields.

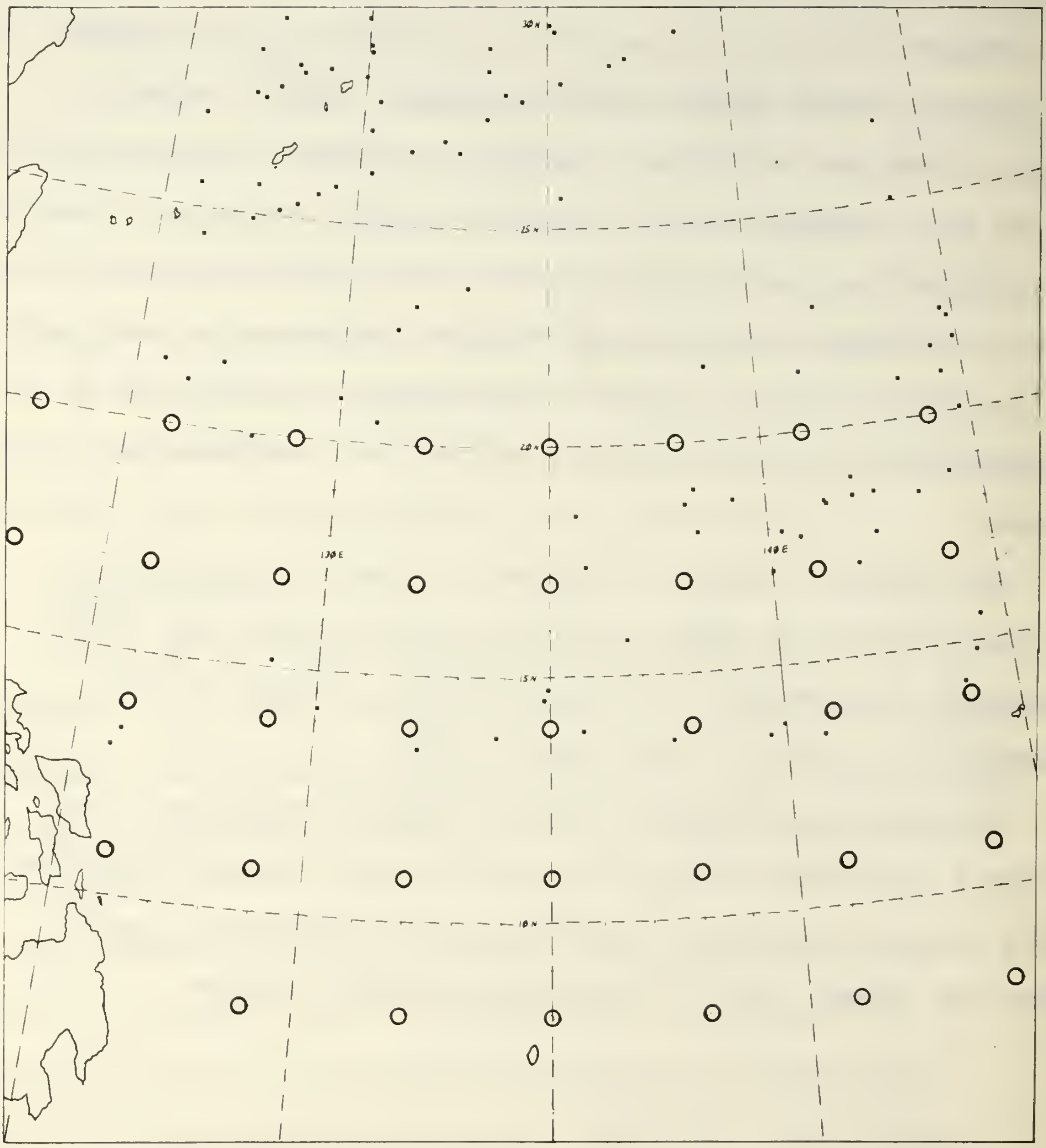

Figure 5. July 1973 BT Observations (squares) and Project OSTroC Sample Positions (circles).

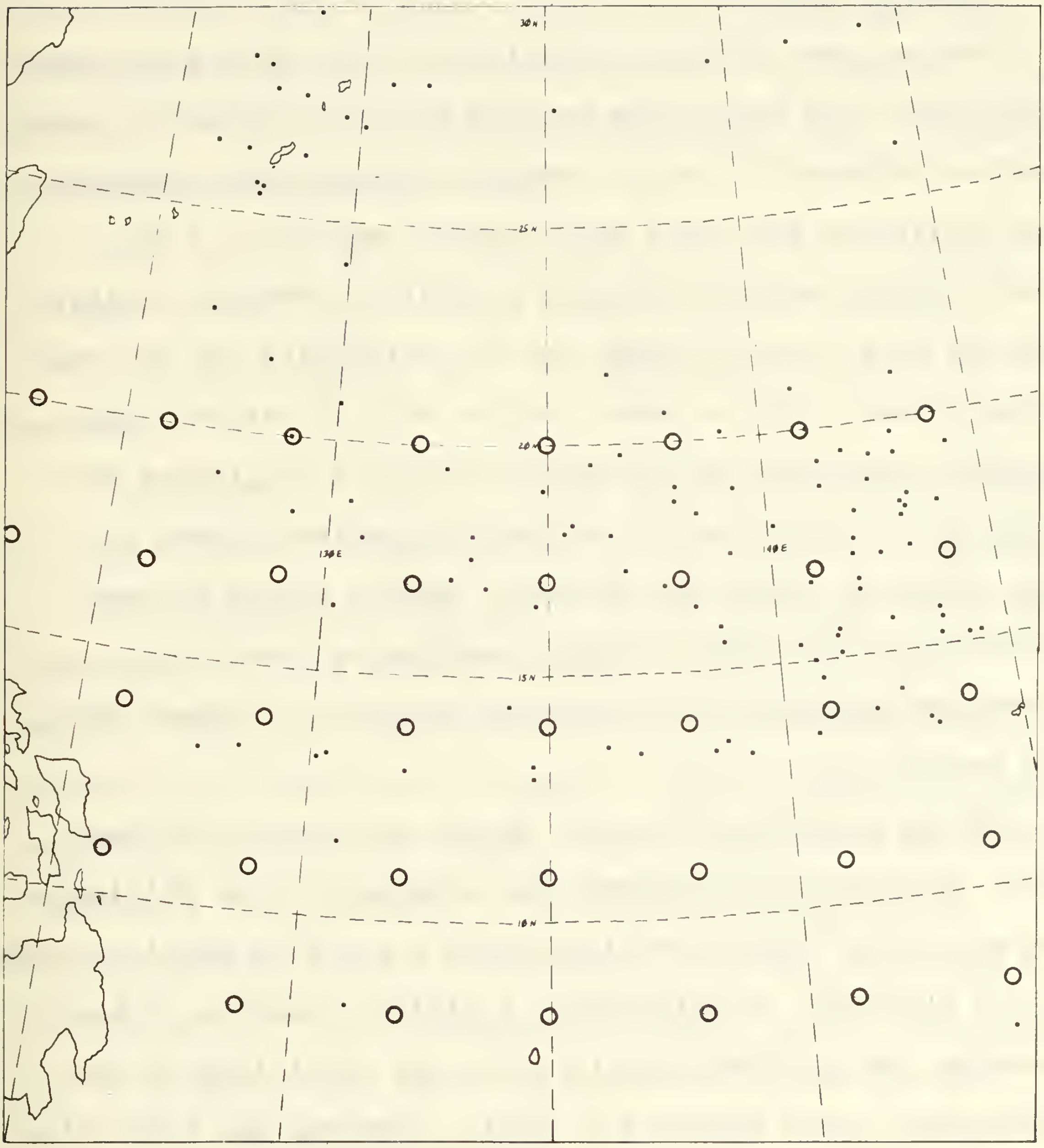

Figure 6. August 1973 BT Observations (squares) and Project OSTroC Sample Positions (circles).

IV. RESULTS

A. GENERAL FEATURES

The analyses of heat potential for 1973 in the two areas considered, the Philippine Sea and the Gulf of Mexico, were handled differently due to various circumstances. Overall, the Philippine Sea had a much broader data base of BT observations than did the Gulf of Mexico. Because of this, ten-day maps could be drawn for the Philippine Sea but only monthly maps could be drawn for the Gulf of Mexico. The seasonal variation in heat potential in the Philippine Sea appeared as a north-south movement of generally east to west isolines, while the spring to summer change in heat potential in the Gulf of Mexico manifested itself as a northward intrusion of a high heat potential "tongue" into the eastern Gulf.

As one contributor to heat potential changes the mean total air-ocean heat exchange was examined in the Philippine Sea and in the Gulf of Mexico, using a study by Hamilton (1971). In the Gulf, in this study, positive isopleths of heat exchange, or net heat gain by the ocean (heat loss by the atmosphere) first appeared in April. Maximum net heat gains of 200 cal/cm^2/day occurred in July. In August, the rate of heating decreased, but remained positive. Cooling began in the Gulf in September, and net heat loss by the Gulf to the atmosphere continued until the following April.

A similar mean pattern of air-ocean heat exchange occurred in the Philippine Sea, where maximum ocean heat gains took place in the summer months. Winter heat losses were much less in the Philippine Sea than in the Gulf of Mexico. Some portions of the Philippine Sea showed a heat gain all year, with greatest magnitude in July.

These results were in good agreement with the observed 1973 HHP trends, which showed increasing heat potential build-ups until August, then the beginning of a decrease in September.

A comparison of four BT traces taken in the large centers of heat potential maximum during 1973 in the Gulf of Mexico and the Philippine Sea (Figure 7) showed that the sea surface temperature of both bodies of water at these positions reached values that approximate 30°C. The Gulf BTs were obtained on 5 August and 16 August. The Philippine Sea BTs were taken on 28 and 29 August. Both areas exhibited similar temperature profiles down to the 26°C isotherm, which appeared between 130 and 150 meters. This was reflected in the similarity of the computed HHP values, 30,200 and 33,800 cal/cm^2-column in the Gulf and 37,500 cal/cm^2-column for both BTs in the Philippine Sea.

Below 26°C the BT traces from the two seas diverged and warmer water was present in the deep Gulf than in the Philippine Sea.

The purpose of this comparison was to determine if the reliable centers of HHP maximums exhibited similar profiles.

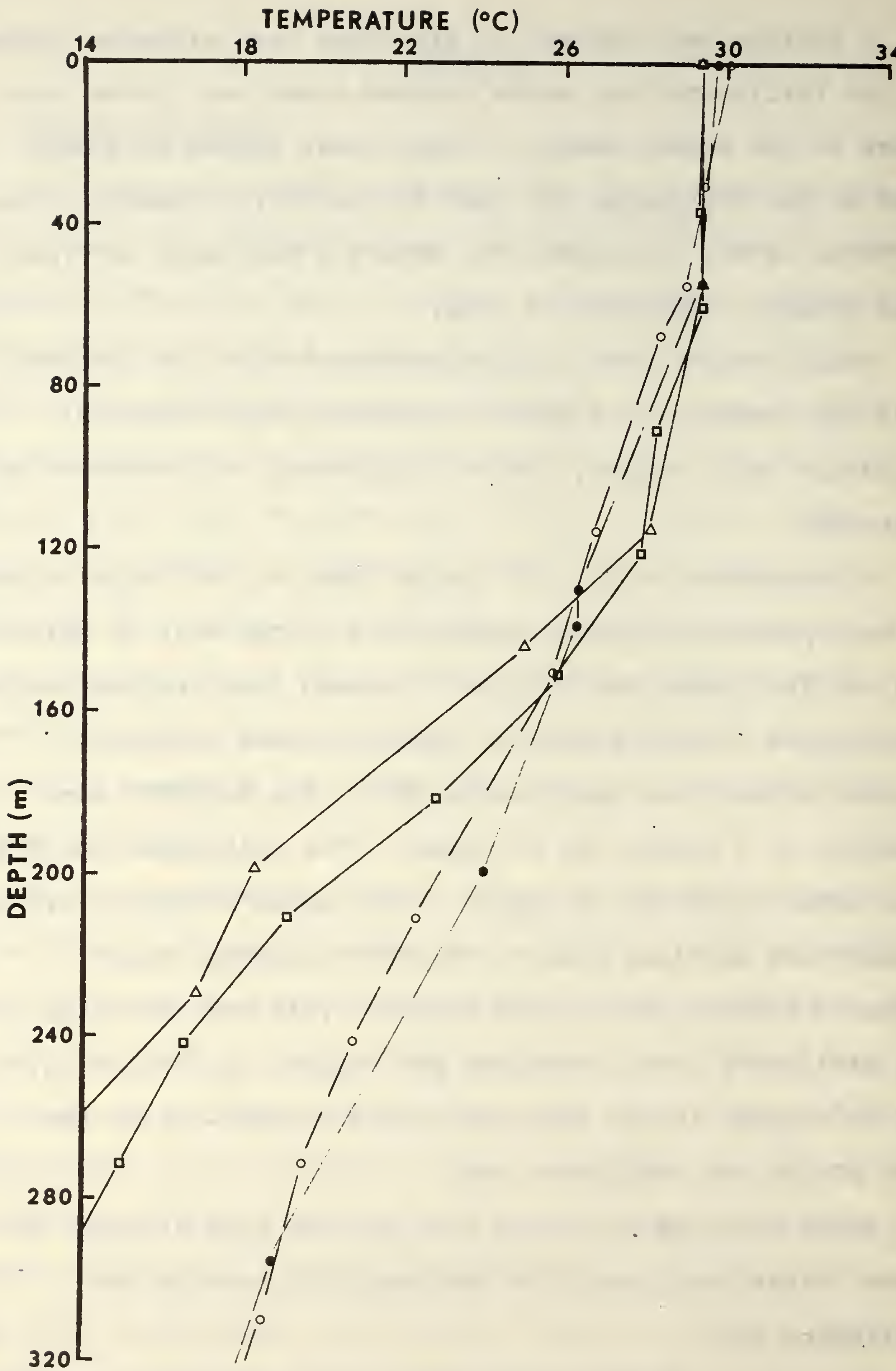

Figure 7. Comparison of Gulf of Mexico (dashed lines) and Philippine Sea (solid lines) 1973 BTs Obtained From HHP Maximum Centers.

While maximum values in excess of 60,000 cal/cm^2-column were observed in small areas of the Philippine Sea, these were based on single BT observations. These could not be explained logically but they were included in the analysis. Based on the 1973 results and Heffernan's [1972] mean maps, maximum values in excess of 40,000 cal/cm^2-column were believed to be unreal.

B. GULF OF MEXICO

1. Monthly Maps

a. Review of sequential monthly maps

The heat potentials present during May are shown in Figure (8). Even at this early time in the HHP season the warm tongue mentioned by Leipper and Volgenau [1972] had begun to thrust up from the Yucatan Channel into the Gulf of Mexico. The high centers still had relatively low values of 15,000 cal/cm^2-column. There did not appear to be any significant break in the warm tongue from south to north.

In the June HHP map (Figure 9) the warm tongue had broadened and deepened to a maximum value of 25,000 cal/cm^2-column. The high center present on the May map at 24°N had moved northward to 26°N.

During July, only 14 BT observations were available. While the amount of BT data was inadequate for showing any significant portion of the entire monthly HHP field, some usefulness was gained from it as shown later by the contour marked July in Figure (11).

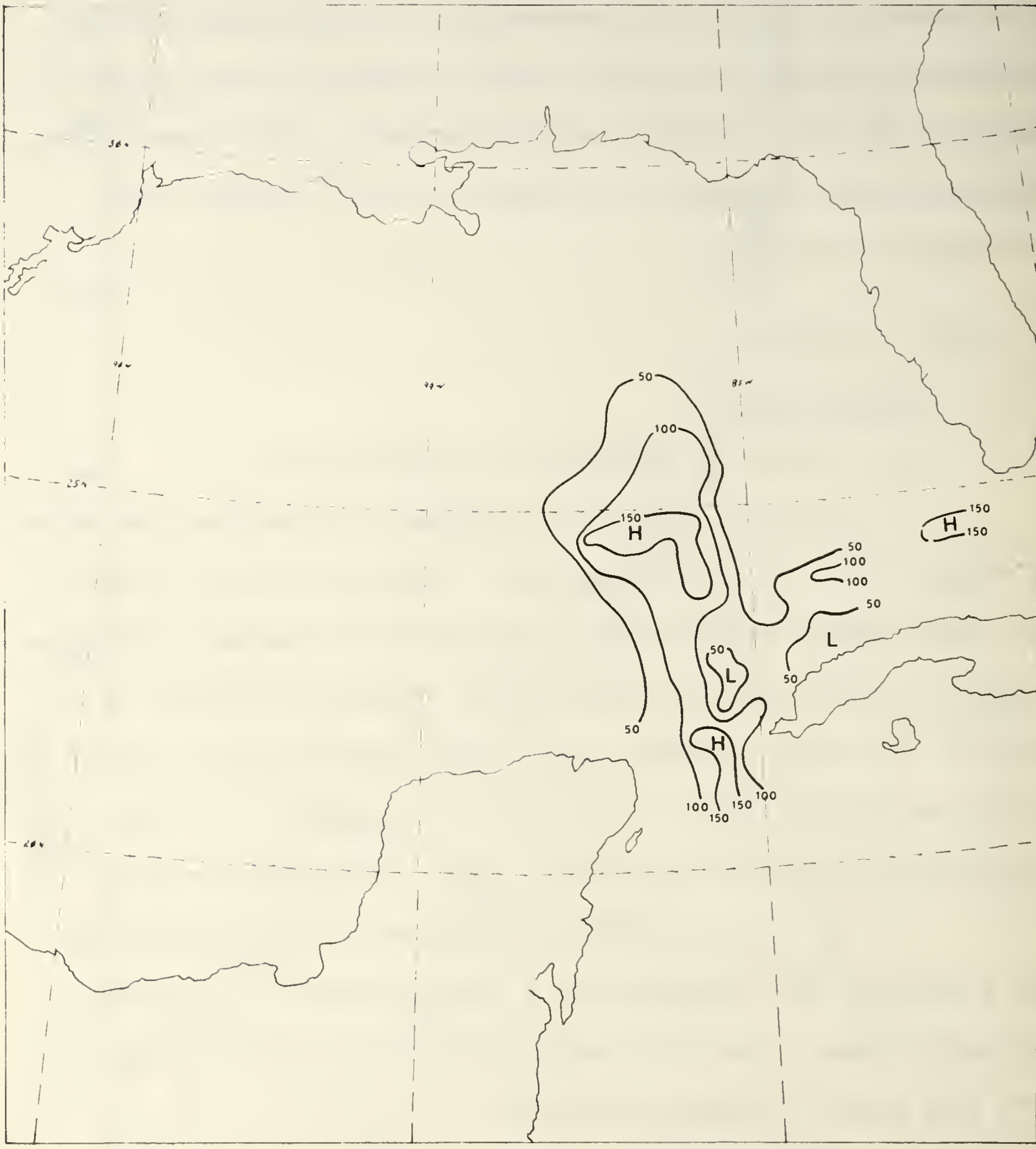

Figure 8. May, 1973 Gulf of Mexico HHP (10^2 cal/cm^2).

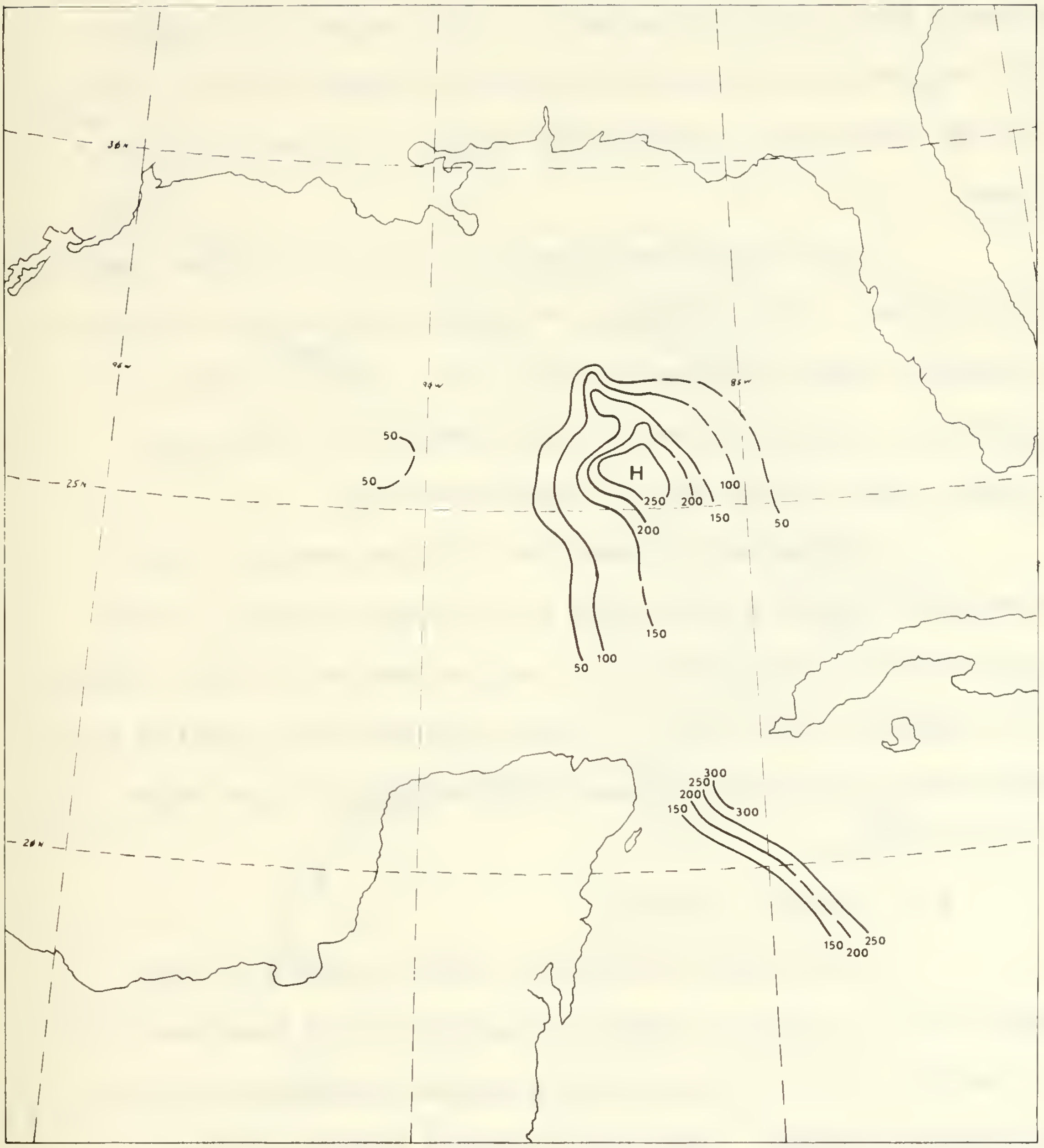

Figure 9. June, 1973 Gulf of Mexico HHP (10^2 cal/cm^2).

The August HHP map (Figure 10) clearly defined two centers of high HHP indicating the existence of an eddy separate from the loop current. This agreed with August 1965 loop pattern observations where Leipper [1970] found that the upper part of the loop broke off from its feeder current.

The maximum centers of 30,000 cal/cm^2-column were similar to the maximums found by Volgenau and Leipper in 1966 and 1968 (Figures 17 and 18). The 1973 data indicated a slightly more northward extent of the HHP northern high center than in 1966 and 1968.

September yielded few BT observations (six). The sparse data did show that the northern extent of the 10,000 calorie line apparently had retreated 55 n.m. south of the August 10,000 line. This reflected the cooling and retreating of the warm tongue associated with the onset of fall and winter.

b. Seasonal changes

The summer build-up of heat content in the eastern Gulf of Mexico seems to result from a combination of two factors, advection and the seasonal variations in air-ocean heat exchange. Heating from the atmosphere has already been mentioned.

The seasonal expansion of a warm-water loop current in the Gulf was studied by Leipper [1970]. Named the spring intrusion, warm water from the Yucatan Current expanded into the eastern Gulf, dividing the Gulf into two

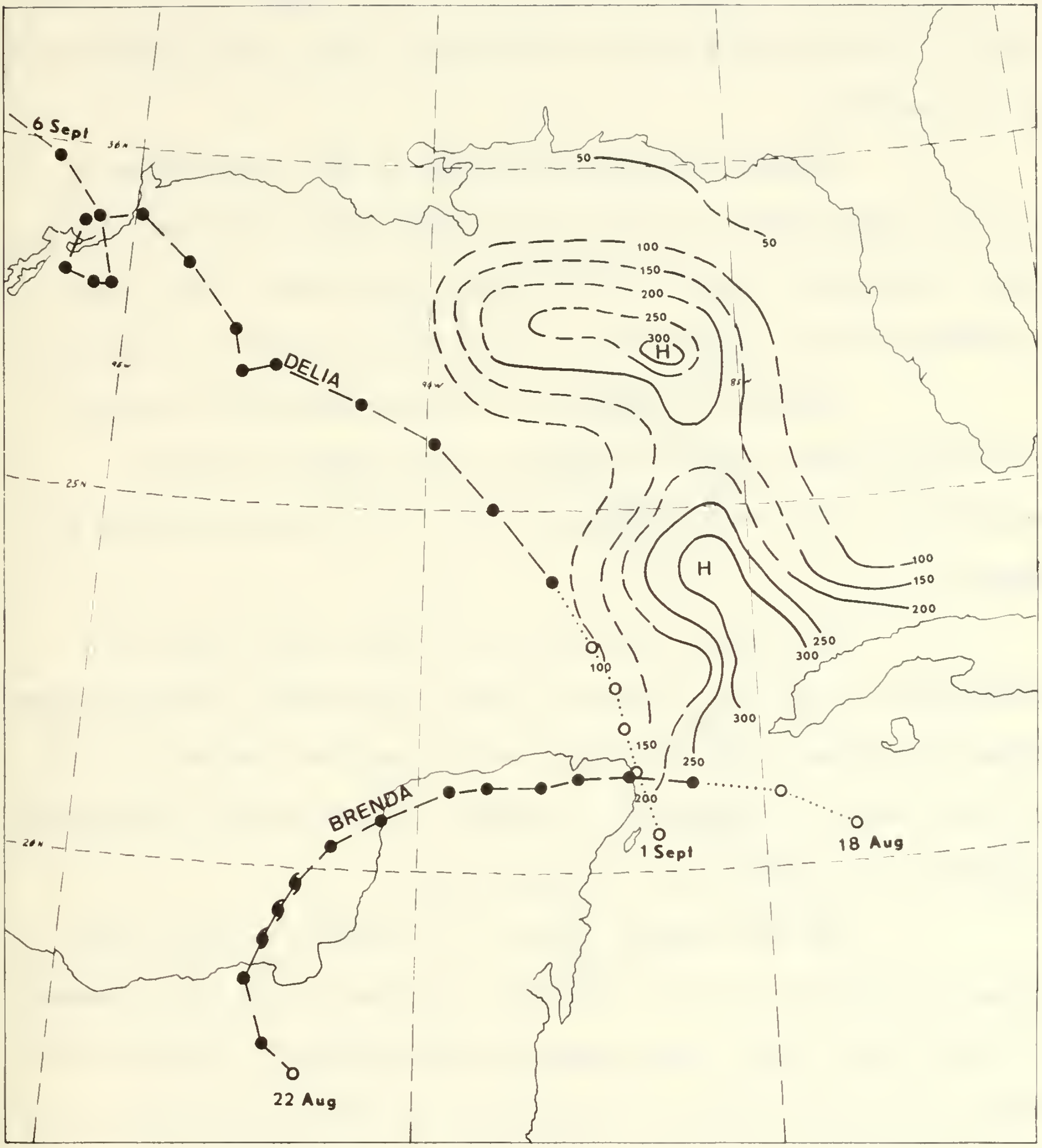

Figure 10. August, 1973 Gulf of Mexico HHP (10^2 cal/cm^2).

separate water masses. The water inside the loop was characterized by higher temperatures and higher salinities than the water found on the outside of the loop, to the left of the current.

Leipper defined the loop by the topography of the 22°C isothermal surface, but since the right-hand loop water was warmer than the left-hand loop water, the loop pattern can also be defined by the heat potential contours.

Figure (11) shows the development and movement of the high HHP tongue throughout the summer of 1973, beginning in May and terminating at its greatest extent in August.

By composite overlays of the 15,000 cal/cm^2-column line from May through August the monthly observations showed a movement of the high heat potential center to the east and north, indicating a growth of the area of high heat potential up through the central Gulf.

The May-August rate of intrusion of this warm tongue northward was 101 km/month obtained from the movement of the 15,000 line, which agrees with Leipper's results. He found an over-all rate of expansion of 65 km per month northward in December through August, but indicated a more rapid intrusion in the spring of 150 km per month from mid-February through March.

Figure (12) compares two BTs, one taken within the warm tongue (Ship B) at 25-50N 85-51W with a HHP of 11,700 cal, the other taken on the left-hand side of the

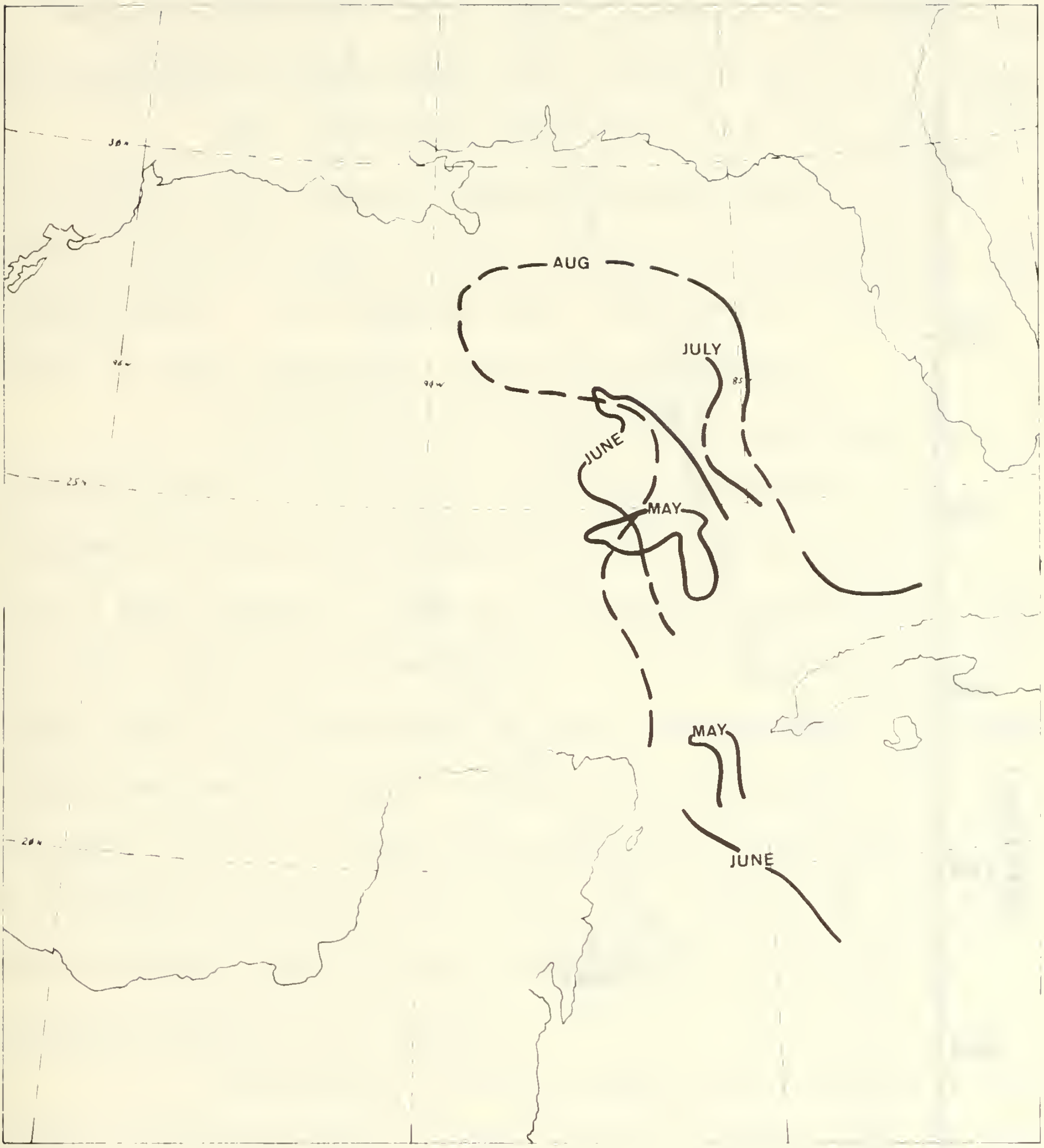

Figure 11. Composite Map of 1973 Monthly Movements of 15,000 cal/cm^2 HHP Isoline in Gulf of Mexico.

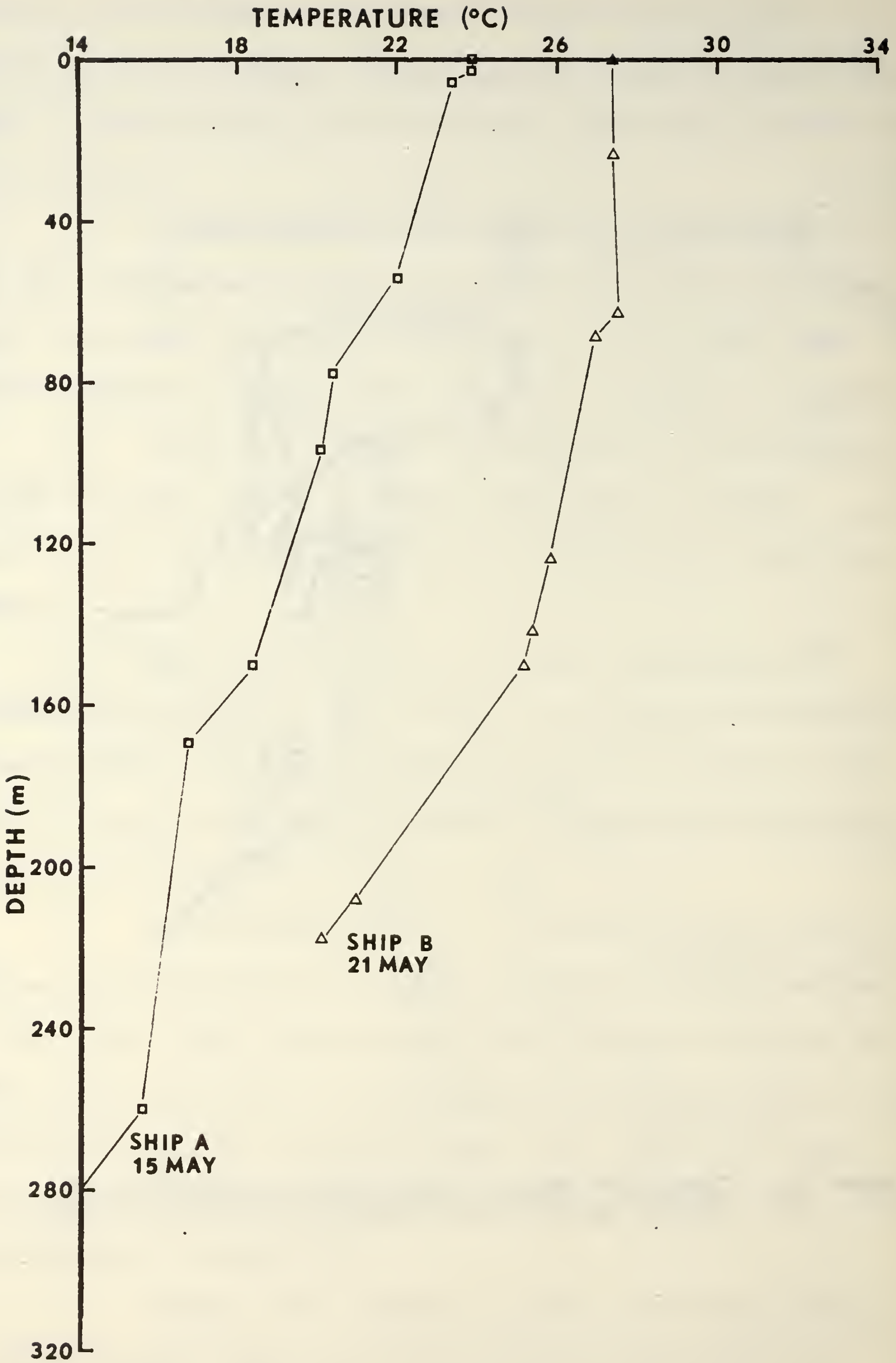

Figure 12. Comparison of Two Gulf of Mexico BTs
(B) Within Loop Current;
(A) Outside Loop Current.

current (Ship A), outside the warm tongue at 25-54N 85-17W with a HHP of 0. The 3-4° separation of the two BT traces to depths in excess of 200m is indicative of the differences between water masses inside and outside of the loop current.

This contrasted with Figure (13), obtained from two BTs in approximately the same location west of Cuba, which illustrated the effects of surface heating during the summer season. The surface water was warmed 3°, yet the water at 160m remained at the same temperature.

Comparison of the August 1973 hurricane heat potential map with the four August maps of Leipper and Volgenau [1972] reflect similarities. The five maps all show a warm tongue of high heat potential extending up into the Gulf from the Yucatan Channel. Best developed in 1966, 1968, and 1973, these years all show heat potential maximum values enclosed by 30,000 cal/cm^2-column isolines. 1967 and 1965, years of lesser HHP development, had highs enclosed by 25,000 cal isolines. The 1973 eddy high is in a slightly more northerly position than the northerly high centers found by Leipper and Volgenau.

The pattern of warm loops which Heffernan [1972] found in his mean maps of HHP in May - September agreed with the 1973 results. Heffernan's HHP maximums were low compared to the 1973 data, not exceeding 15,000 cal/cm^2-column. A possible explanation for this will be mentioned later.

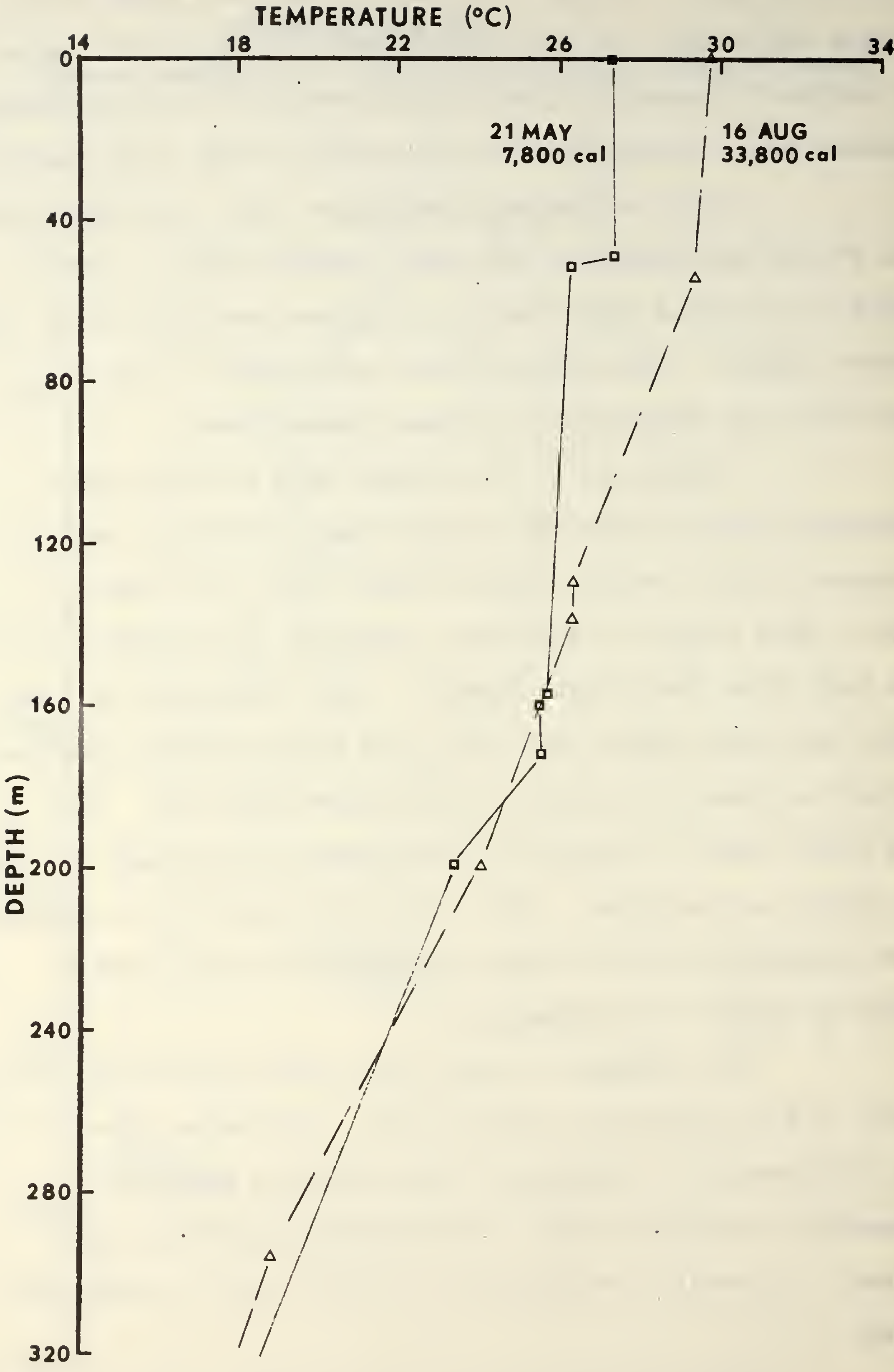

Figure 13. BTs Illustrating Seasonal Change in HHP Due to Surface Heating.

2. Tropical Storm Activity

a. Hurricane Brenda

With only one hurricane occurring, 1973 was a year of low hurricane activity in the Gulf of Mexico. Table (2) shows that the mean number of hurricanes and tropical storms appearing per year in the Gulf is almost four. The 1973 hurricane, Brenda, appeared only near the periphery of the Gulf.

The preliminary report on Brenda [Pike 1973] stated that she formed from a tropical depression over the Yucatan Channel on 18 August and passed inland over the northeastern coast of the Yucatan Peninsula on the 19th. Early on the 20th the storm emerged into the Bay of Campeche, and here she steadily intensified to hurricane status (Figure 10). Landfall was made on the 21st about 35 miles west of Ciudad del Carmen. About this time the 70 knot central winds began to diminish rapidly and Brenda shortly thereafter diffused into a broad, rainy low pressure area.

Of note is the fact that Brenda grew into a hurricane only when she moved over a water area and that she lost her hurricane force when she moved inland again.

The August BT data from the portion of the Gulf over which Brenda passed consisted of only one report, which indicated a heat potential of 3700 cal/cm^2-column.

Figure (14) shows two BT profiles, one before and one after Brenda, taken in the vicinity of the hurricane. On 22 July, a month prior to the hurricane, the first BT was

Table 2. Yearly Number of Tropical Storms and Hurricanes Appearing in the Gulf of Mexico, 1941-1971.

YEAR	# HURRICANES	# TROP. STORMS
1941	3	2
1942	3	0
1943	2	0
1944	2	2
1945	2	2
1946	1	2
1947	4	4
1948	3	1
1949	3	1
1952	0	0
1953	1	2
1954	2	1
1957	1	4
1958	0	2
1959	1	5
1960	2	3
1961	1	1
1962	0	0
1964	2	2
1965	1	2
1966	2	1
1967	2	0
1968	1	2
1969	3	1
1970	3	3
1971	2	0
AVERAGE	1.8	1.6

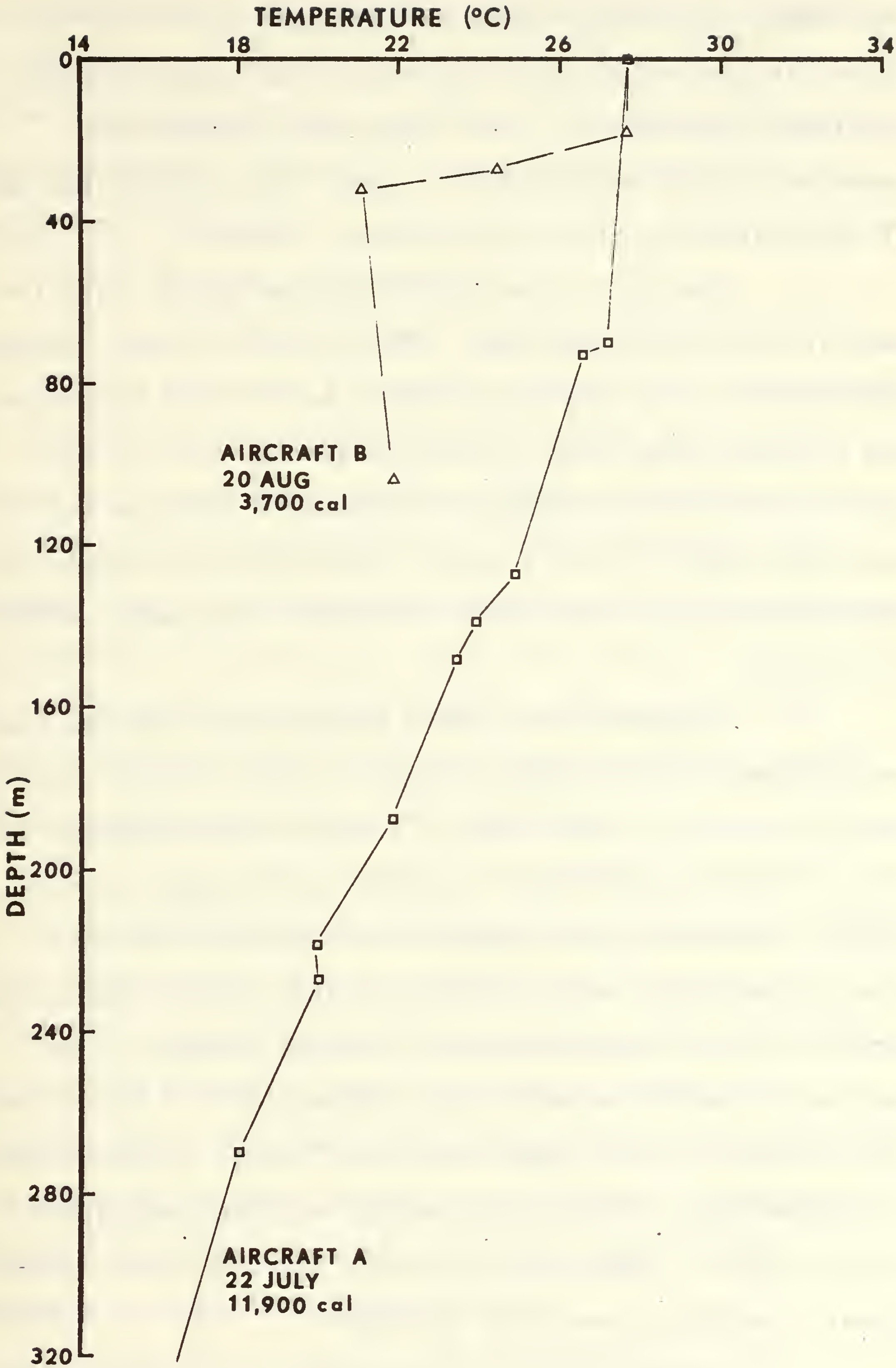

Figure 14. BT Profiles Prior to (A) and During (B) Hurricane Brenda.

obtained in the Bay of Campeche (Aircraft A) and on 20 August the second BT was dropped into the center of the hurricane (Aircraft B). The sea surface temperature appeared to have held steady at about 28°C between the two BT observations despite the arrival of Brenda.

The heat potential at this second BT location was, as previously mentioned, 3700 cal/cm^2-column. Since it was dropped in the eye of the storm half of the hurricane had already passed over. Using an average rate of heat removal of 4,000 cal/cm^2/day [Volgenau 1970] there was sufficient heat at this position to sustain the hurricane approximately one more day if it became stationary, which it did not.

Leipper [1964] found decreases in the sea surface temperature after hurricane passage in all his BTs. This would be expected since heat is lost to the atmosphere at a rate of 4,000 cal/cm^2/day. However, no decrease in sea surface temperature was apparent with Brenda from this single observation when compared to the single reading made earlier as should have happened with the passage of the hurricane over the warmer ocean [Jensen 1970]. The BTs were not obtained from the same position, further complicating the comparison. There is no readily apparent explanation for the lack of temperature decrease between these observations. One might have been in error.

Leipper [1964] in his study of Hurricane Hilda, found a decrease in the mixed layer depth associated with

upwelling at the hurricane eye. A comparison of Brenda's two BTs showed a decrease in the mixed layer depth, an indication of upwelling. However, the 20 August BT with an inversion between 32 and 106 m depth would seem to be of questionable validity.

b. Tropical Storm Delia

Although there was only one hurricane in the Gulf in 1973 there was a tropical storm, Delia, which passed over the main body of the Gulf. Spawned in the Yucatan Channel on 1 September, the storm began a northwestward path across the Gulf (Figure 10). The disturbance was upgraded from a tropical depression to a tropical storm on the morning of the 3rd in an area over the Gulf where the HHP was about 10,000 cal/cm^2-column. Early on the 5th landfall was made near Galveston, Texas, where the storm stalled, then moved inland and dissipated.

While Delia's track and intensity seemed to be primarily influenced by a large anticyclone over the Eastern United States and a cyclonic circulation over the Gulf [Clark 1973], she did pass over a region of the Gulf which historically showed low heat potentials [Leipper and Volgenau 1972]. The possibility exists that Delia's passage over areas of low heat potential provided one explanation for her failure to intensify. Data for 1973 was not available to support or disprove this.

3. Hurricane Heat Potential Field (Gulf of Mexico) and Tropical Storm Activity 1965-1968

Comparison of Heffernan's August monthly mean HHPs with the oceanic HHPs computed by Volgenau [1970] for designated August cruises in the years 1965-1968 showed that the mean values were dramatically lower than those observed in the Gulf of Mexico. While mean heat potential values did not exceed 15,000 cal/cm^2, the 1965-1968 HHP maps showed large areas exceeding 20,000 cal/cm^2, with maximum values in two years in excess of 30,000 cal/cm^2.

The Heffernan heat potential means were computed for one-degree quadrangles. However, Volgenau has shown that the warm tongues present vary yearly, both in amount of heat content and in location. Both the Volgenau analyses and the 1973 Gulf maps showed that the horizontal gradients between the warm areas and the areas of lower heat potential were variable but often they were very strong. This may indicate why the Heffernan maximum HHP values for the Gulf of Mexico were lower than the yearly data; averaging values for a location where a high maximum potential exists one year and a low potential exists another year due to shifting of the current patterns gives low maximum HHP values.

Hurricane and tropical storm activity in the Gulf for these four years was about average, between three and four storms per season (Table 2).

The August HHP fields of Volgenau in the Gulf during the individual years 1965-1968 were studied collectively;

then the data for individual years were related to the storms occurring in those years.

The map showing lowest August heat potential was in 1967. The 1965 map showed the next lowest value. 1966 and 1968 maps showed markedly higher values in heat potential than those from the other two years. Subjectively, 1968 showed a slightly higher overall heat potential than did 1966 (Figures 15-18).

Volgenau obtained his BT information from four scientific cruises [Leipper 1968] which gave excellent coverage to the northern and eastern portions of the Gulf. However, noticeably absent was heat potential information for the entire southwest quadrant of the Gulf.

This was unfortunate, since during the four years under consideration, major storm events took place in this part of the Gulf. For example, in 1968 Candy intensified from a tropical depression to a tropical storm while moving northward through the western Gulf.

In 1966 Tropical Storm Hallie also formed in this southwestern part of the Gulf. Two weeks later, Hurricane Inez passed through this region. Of note is the fact that Inez reached her maximum intensity with winds of approximately 175 m.p.h. after brushing the Yucatan Peninsula and entering into the western Gulf of Mexico. A study was made of the effect of Inez upon the coastal waters of the western Gulf by Franceschini and El-Sayed [1968]. Physical, chemical

and biological changes were studied. Sea surface temperature drops and increases in the mixed layer depth were observed after the hurricane passage.

1967 saw the passage of Hurricane Beulah over the waters of the western Gulf. After moving over the Yucatan Peninsula, Beulah's winds intensified from 85 knots to 140 knots while passing through the western Gulf of Mexico on her path to the Texas-Mexico border.

Hurricane Fern originated in the southwestern Gulf of Mexico two weeks following Beulah but rapidly weakened as it moved through the area. This hurricane moved over cooler water in the wake of Hurricane Beulah [Sugg and Pelissier 1968] which may explain, at least in part, the surprising decrease in intensity which was observed.

All of these instances serve to accentuate the importance of this neglected region of the Gulf, in particular its importance as a probable influence on tropical storms and hurricanes affecting the Texas and northeastern Mexico coasts.

The data from which Volgenau obtained his August HHP charts provided excellent coverage of the central and eastern Gulf regions. A survey of storm tracks and intensities and their relation to high and low areas of heat potential yields some interesting comparisons.

1967, the lowest in heat potential of the four years, had no storms passing through the central and eastern Gulf (Figure 15). However, this fact cannot be assumed to indicate a causal relationship.

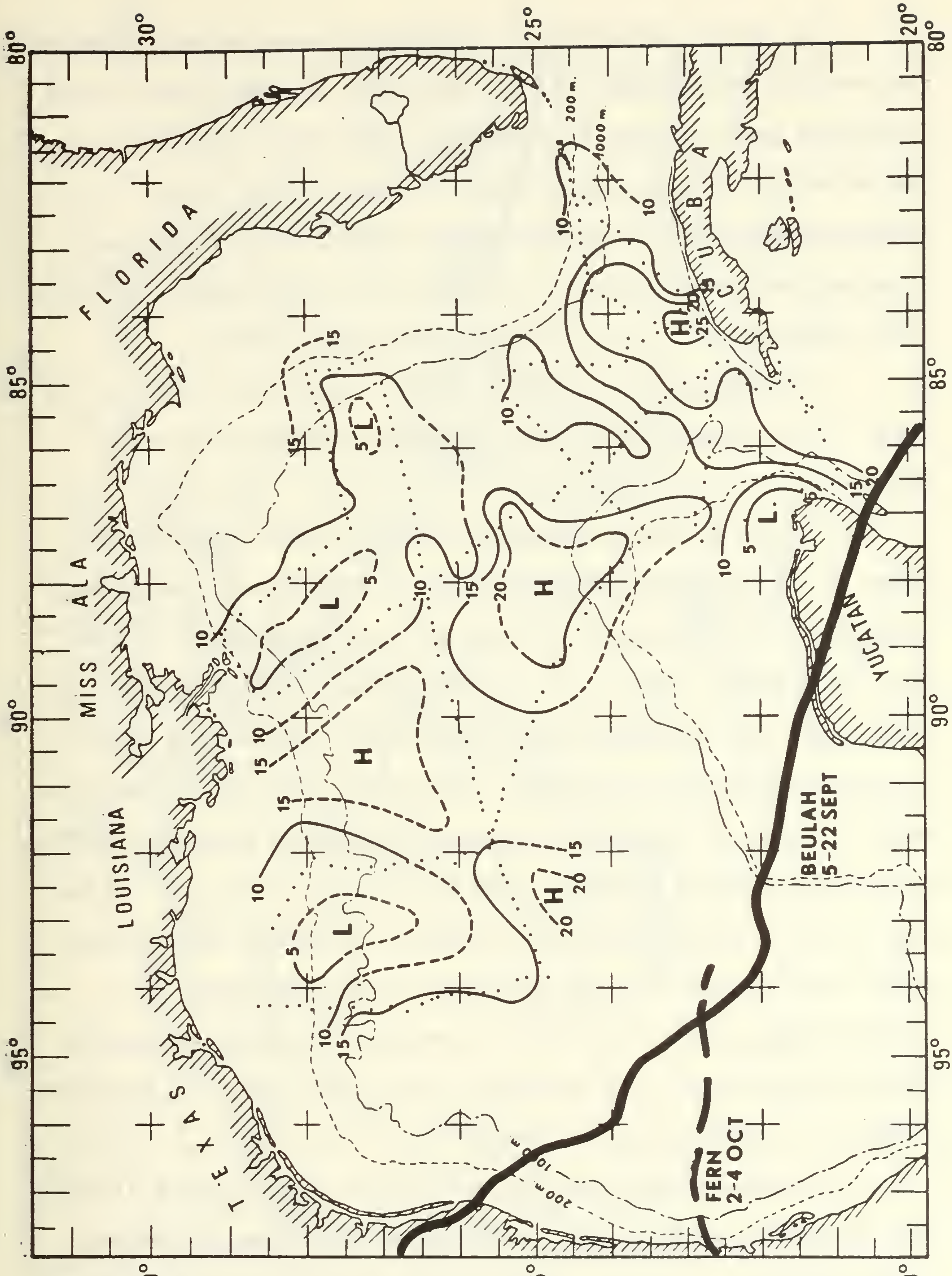

Figure 15. Composite of August 1967 HHP in Gulf of Mexico [Volgenau 1970] and 1967 Storm Tracks.

In early September of 1965, Hurricane Betsy traversed the central Gulf (Figure 16). Over most of its track it was traveling over an area of unusually high heat potential in the mid-Gulf. Betsy struck the Louisiana coast with devastating winds and storm tides. Grand Isle, Louisiana recorded estimated gusts of 160 m.p.h. Total damage due to Betsy approached 1.5 billion dollars [Sugg 1966].

The ferocity of Betsy possibly can be attributed in part to its passage over the unusually high heat content waters of the central Gulf.

Tropical Storm Debbie developed from a depression which moved northward from Yucatan on the 25th of September. Tropical storm intensity was reached on the morning of the 28th in mid-Gulf, but further intensification did not occur. Sugg noted the influx of drier and cooler air moving into the circulation as the primary factor in the lack of development. A plot of Debbie's track over Volgenau's heat potential field reveals that the storm skirted to the west of the high heat potential region for August and moved over waters where the HHP was only 15,000-20,000 cal/cm^2-column. Additionally, Hurricane Betsy's previous passage through the central Gulf would have served to lower the value of the heat potential fields along her track.

Hurricane Alma was an early (4-14 June) storm of the 1966 hurricane season. Her capricious track was an enigma to forecasters. Passing over western Cuba (Figure 17), she headed generally north, then veered to the northwest to

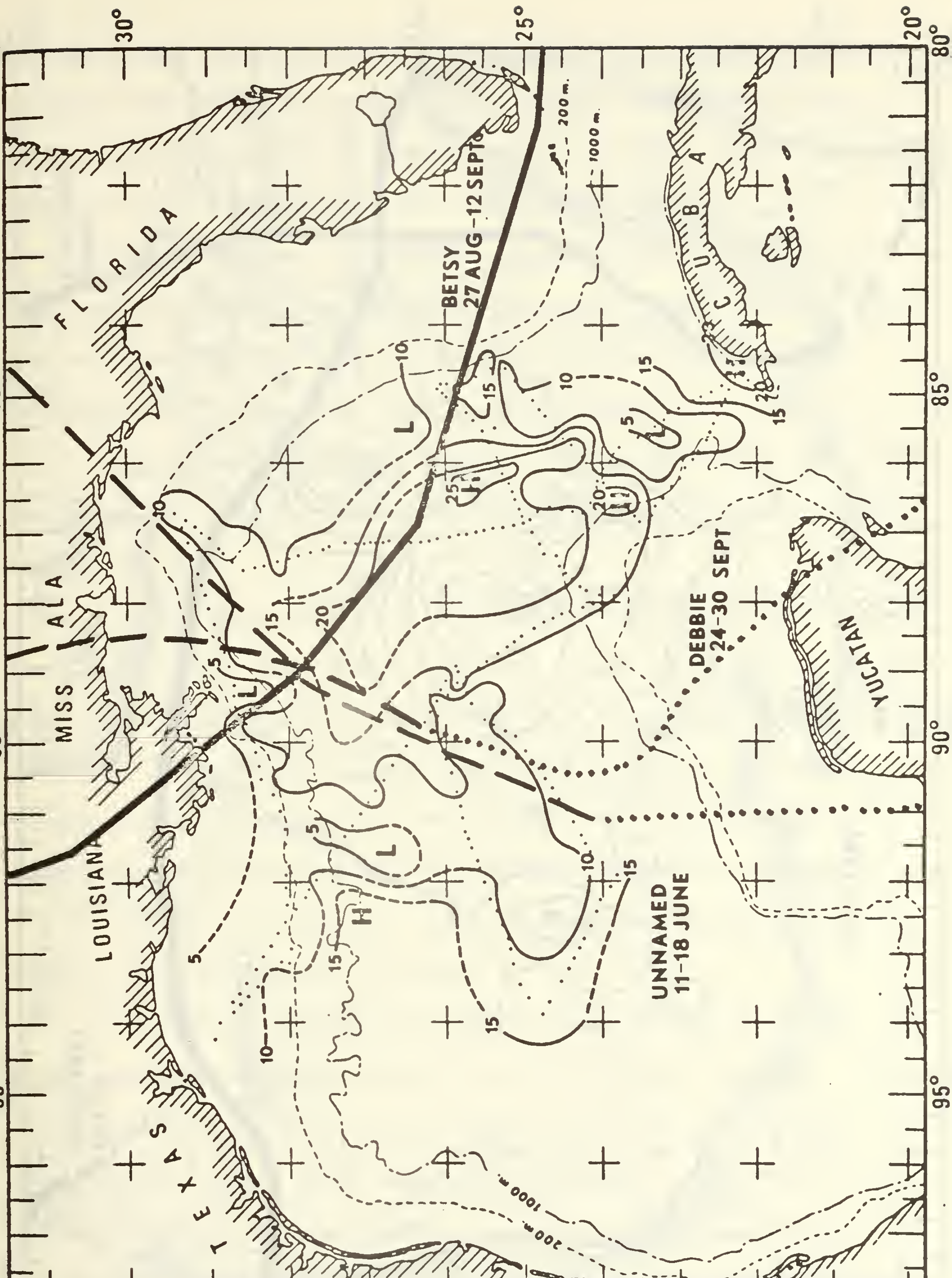

Figure 16. Composite of August 1965 HHP in Gulf of Mexico [Volgenau 1970] and 1965 Storm Tracks.

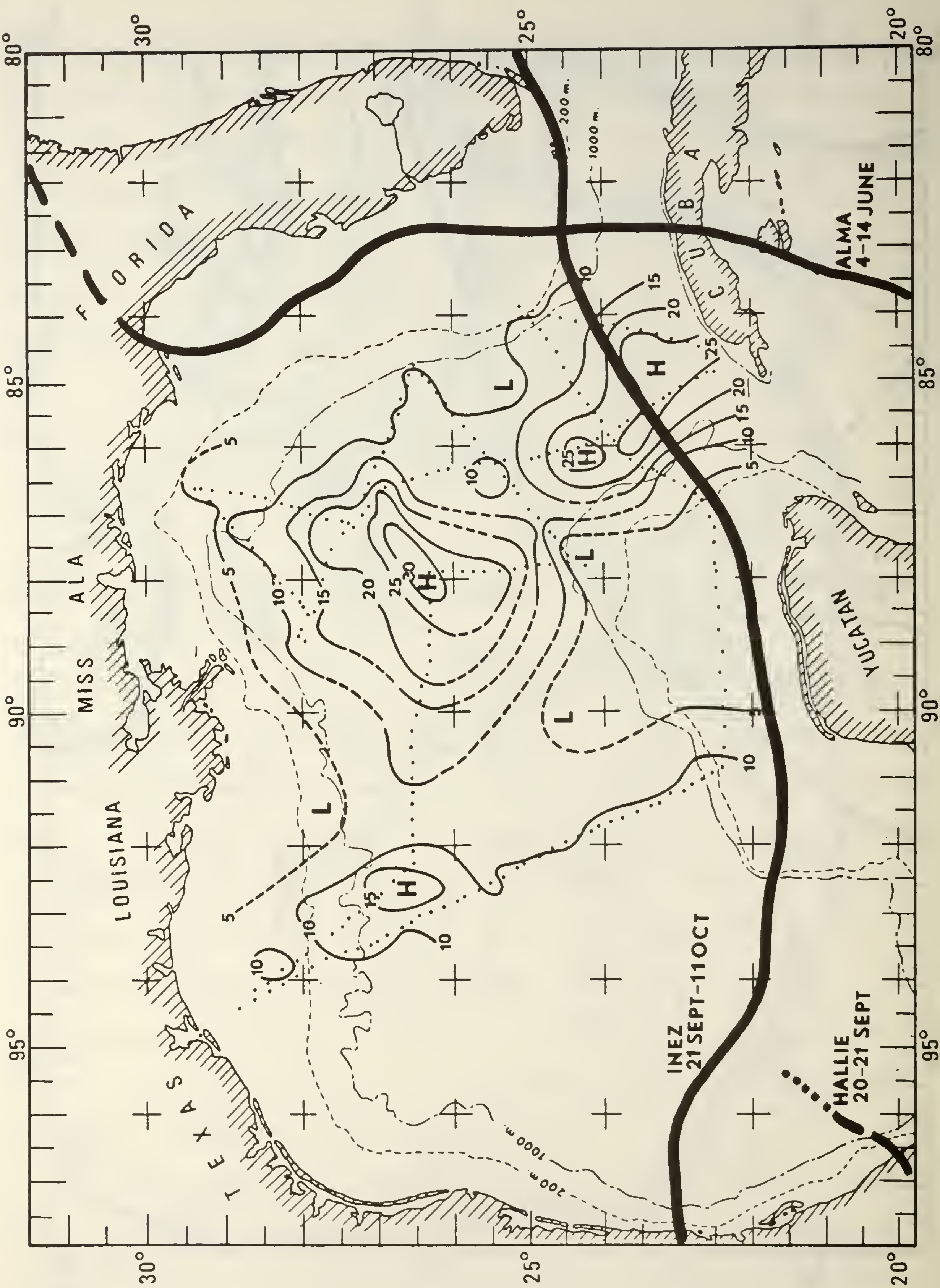

Figure 17. Composite of August 1966 HHP in Gulf of Mexico [Volgenau 1970] and 1966 Storm Tracks.

parallel the Florida west coast. Her track was well to the east of the warmest waters in the Gulf, yet she was not influenced by the high-level pressure patterns until reaching the extreme northern Gulf [Sugg 1967].

Late in the 1966 season, Inez crossed normal to the line of high heat potential in the eastern Gulf (Figure 17) intensifying as she moved. Greatest intensity was not reached until she was in the western Gulf.

1968, the year of highest heat potential of the four analyzed by Volgenau, had two storms of significance in the eastern Gulf.

Hurricane Abby touched the western tip of Cuba as a tropical storm, then moved into the Gulf, where she slowed down and intensified to hurricane force northwest of the Dry Tortugas (Figure 18). This early in the year, the warm tongue of water sometimes present in the eastern Gulf had just begun to develop, and heat potential values were low.

Abby did intensify over an area where the HHP was higher than the adjacent areas.

Hurricane Gladys, the final Gulf storm of 1968, moved through the same area as that traversed by Abby. The track was to the east of the high heat potential centers of the eastern Gulf. Sugg and Hebert [1969] suggest that the path of Gladys was controlled by upper air circulations.

Overall the comparison of the tropical cyclones to Volgenau's HHP fields proved to be inconclusive. Some correlations were indicated between hurricane intensification

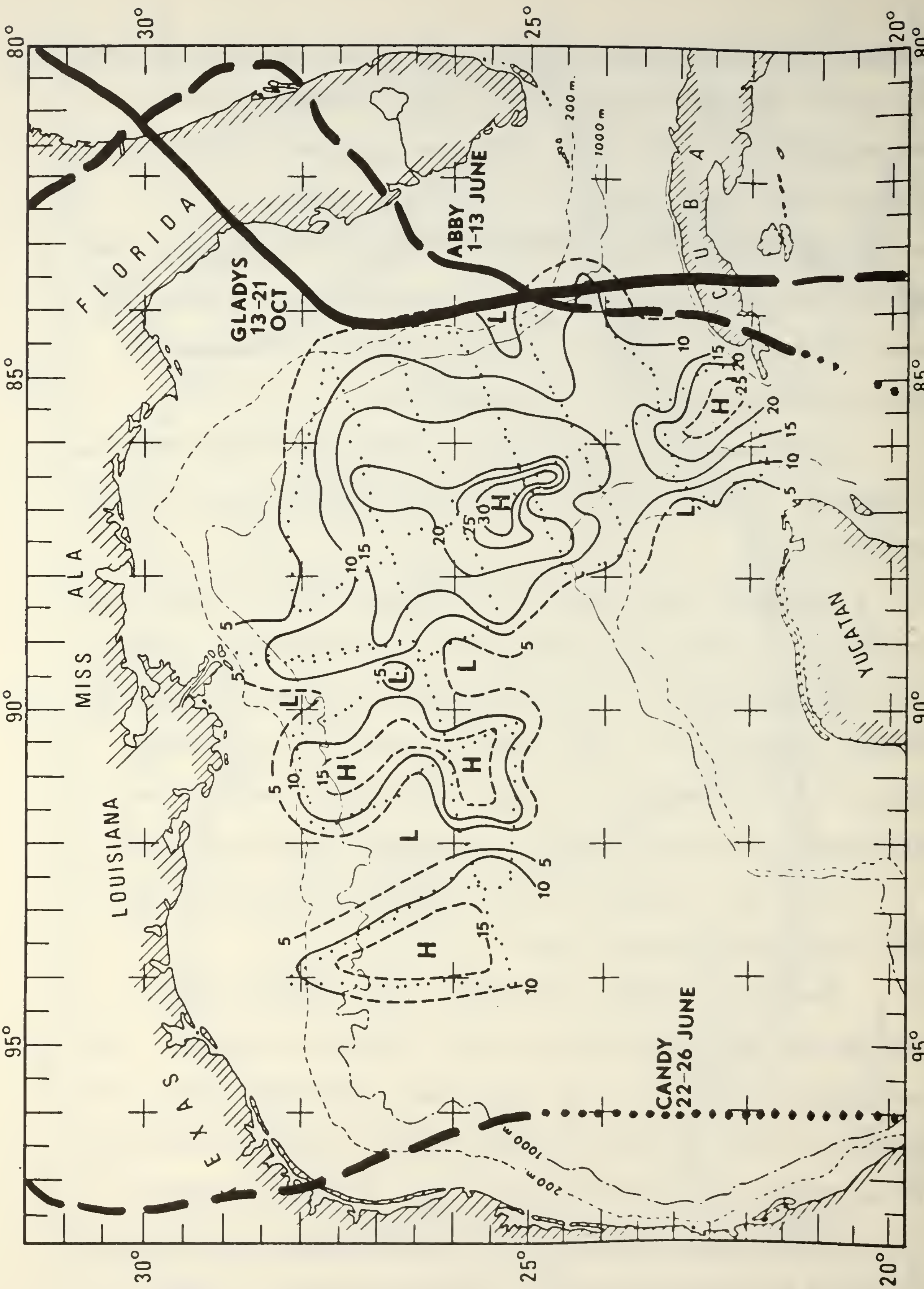

Figure 18. Composite of August 1968 HHP in Gulf of Mexico [Volgenau 1970] and 1968 Storm Tracks.

and the August HHP fields. However for other cases in this general survey the storms did not seem to be influenced by the heat potential.

One problem arose because each year all the tropical storms and hurricanes for that season were compared to the heat potential fields existing in a two-week period in August. The 1973 seasonal results showed that the heat potential patterns shift and undergo intensity changes throughout the summer season. The August HHP maps are truly representative of only the August period, but data were not available for other periods.

C. PHILIPPINE SEA

1. Monthly Maps

a. Sequential monthly development

The 1973 isolines of HHP in the Philippine Sea showed a group of nearly east-west bands extending across the maps.

Each month was divided into three ten-day segments. A sequence using only the first ten-day period of each month, May through September, is included as Figures 19-23. The first ten-day period was included because sufficient observations were taken in this period to provide a continuity in sequence. This was not the case in the mid-monthly and late-monthly periods. These are compared to monthly mean maps for all previous years prepared by Heffernan and included here as Figures 25-29.

The HHP field for 1-10 May 1973 as shown in Figure (19) is incomplete, due to a sparsity of data. The isolines show a marked north-south trend, which contrasts sharply with the mean map for the month (Figure 25). The high center located at 19°N 135°E is based on only a single BT observation, and as such is suspect.

The 1-10 June map (Figure 20) shows an increase in the heat content of the Philippine Sea, evidenced by the appearance of 20,000 and 25,000 cal/cm^2-column isolines. These extend in an east-west direction, in conformity with the mean HHP map for the month (Figure 26). A number of small high centers appear on the ten-day 1973 map. The high center at 15°N 135°E is the only center to show persistence from month to month, and of the several small highs, is the only one based on more than one BT observation.

The July ten-day map for 1973 (Figure 21) discloses additional warming, and 30,000 and 35,000 isolines of HHP first appear. The small high centered at 15°N 135°E is still present. This small high is based on three BT observations, giving it further credence. The warm 30,000 calorie band appearing on the July mean map (Figure 27) only has its northern boundary defined on the ten-day map for July 1973 due to an absence of data south of 12°N.

The 1-10 August 1973 map (Figure 22) presents a complex pattern of spotty highs and lows. The convoluted 35,000 contour had reached its most northerly extent. Each BT taken in the center of an anomalous high or low was

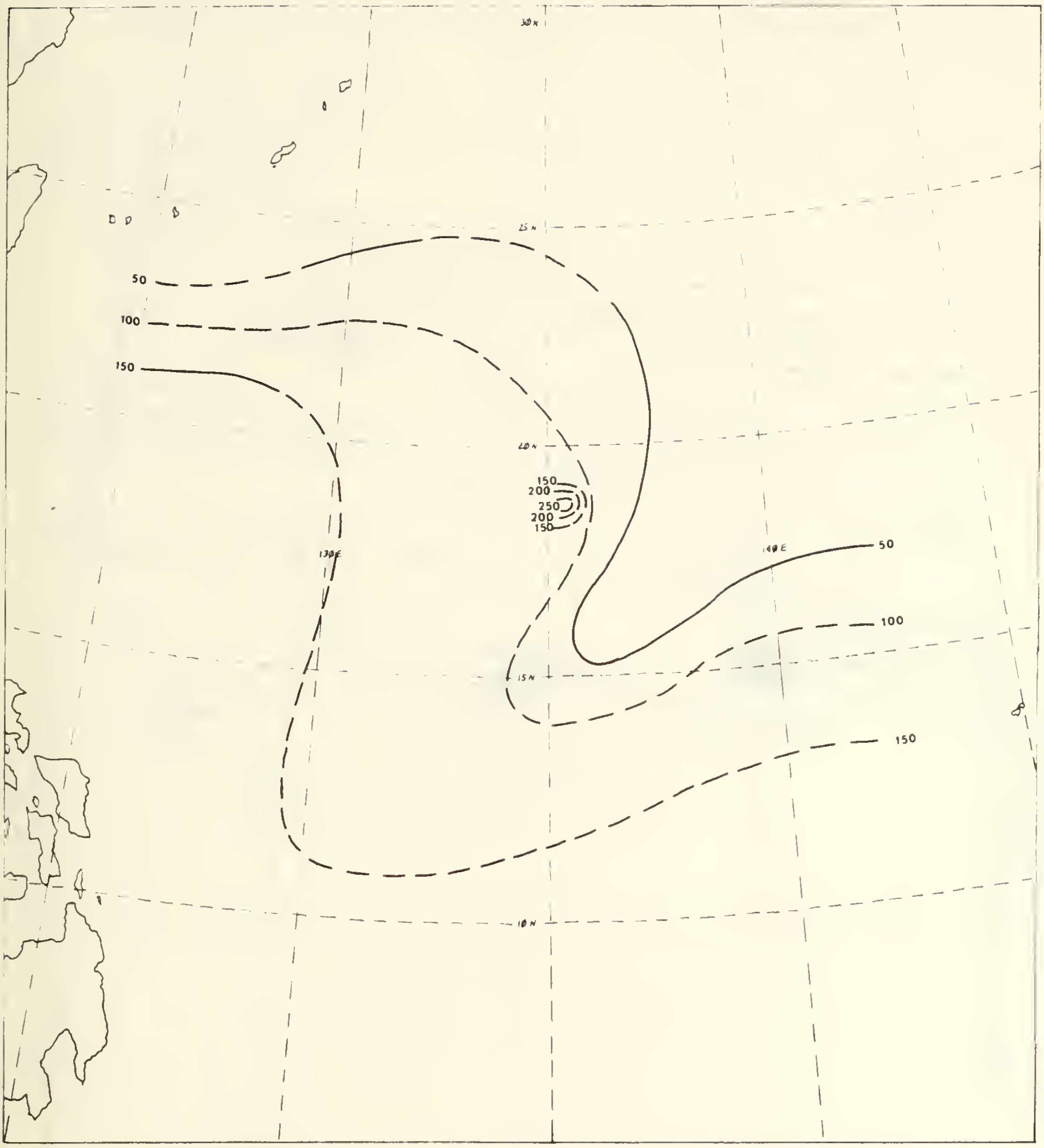

Figure 19. 1-10 May, 1973 Philippine Sea HHP. (10^2 cal/cm^2)

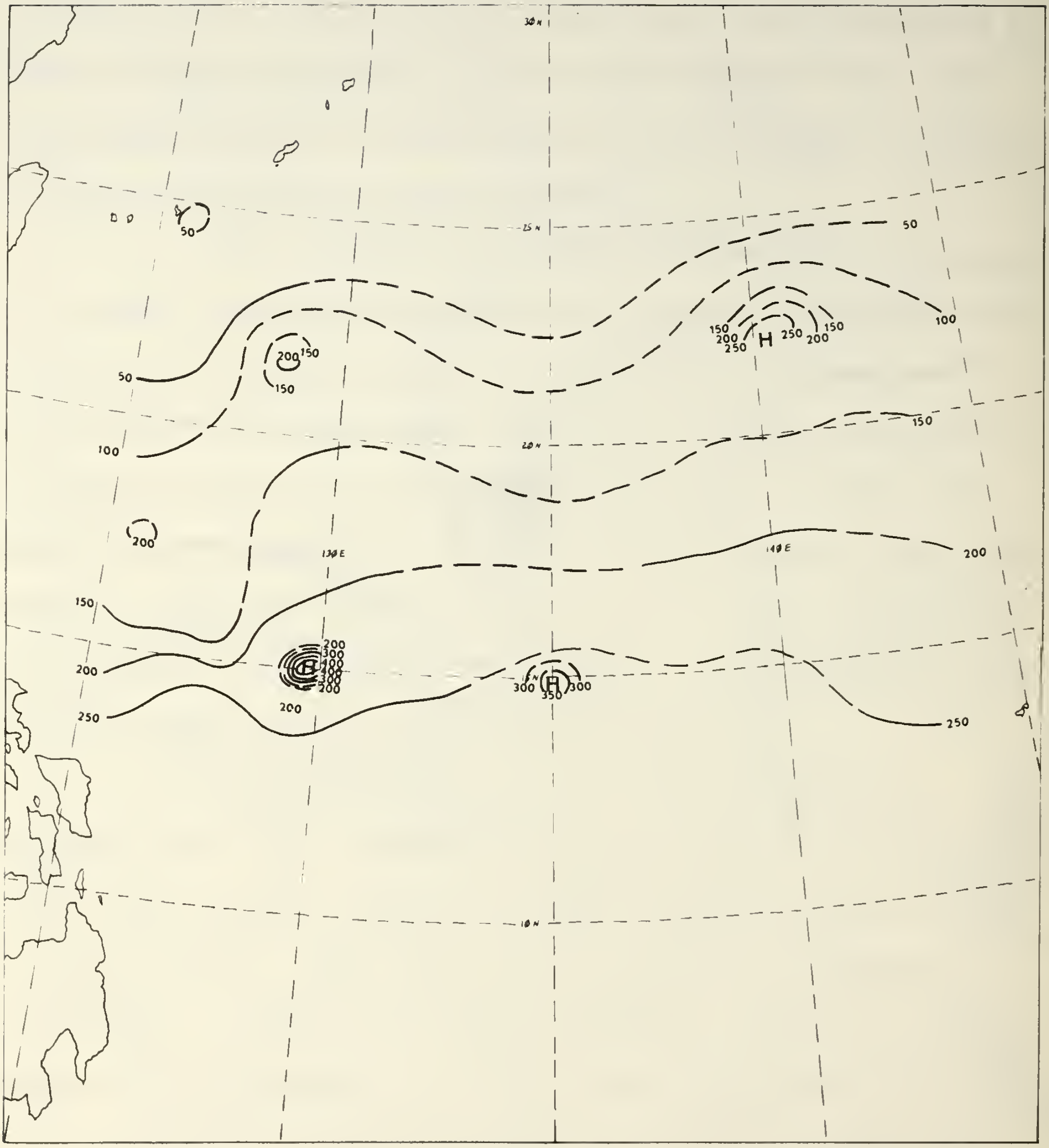

Figure 20. 1-10 June, 1973 Philippine Sea HHP.
(10^2 cal/cm^2)

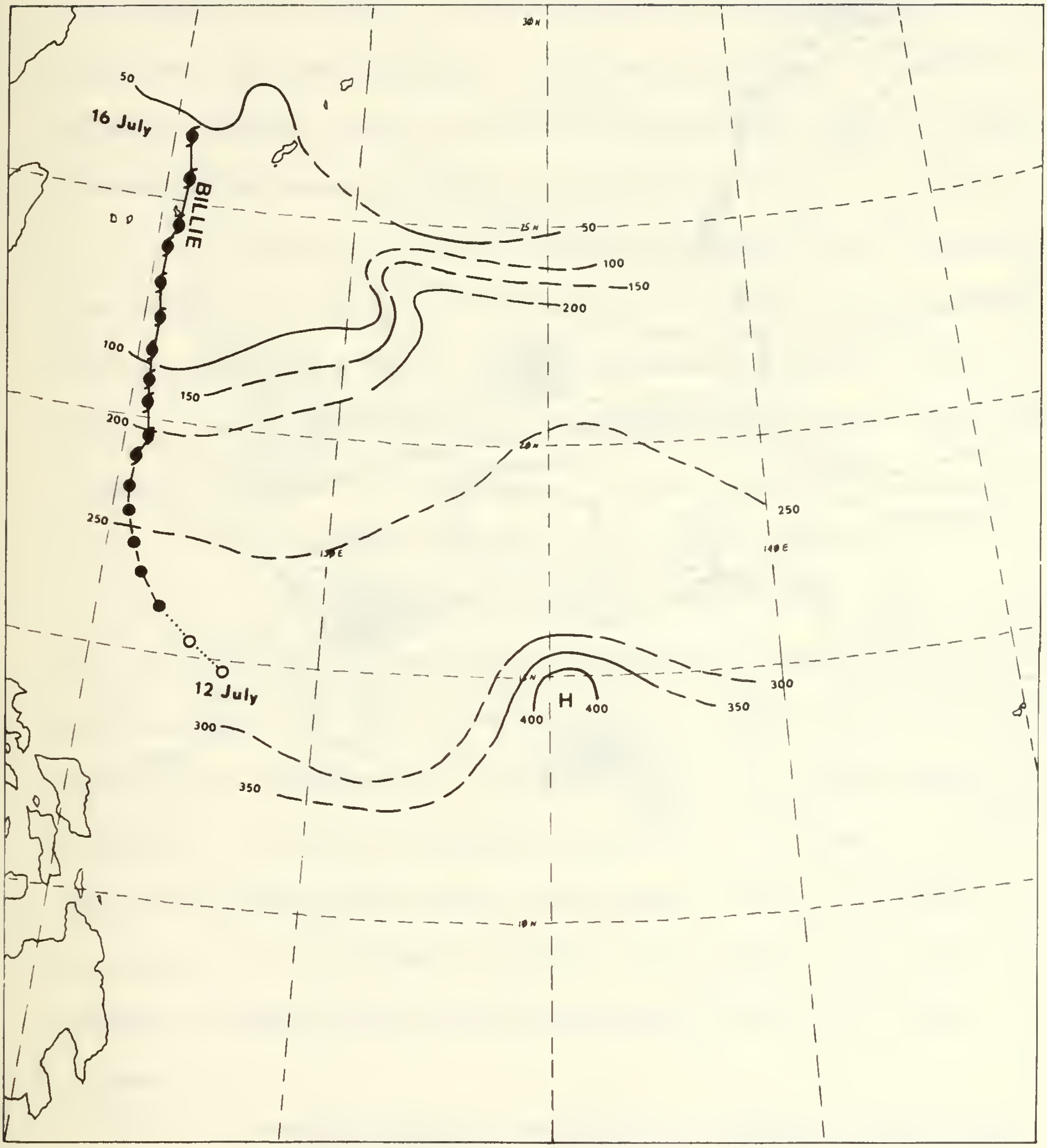

Figure 21. 1-10 July, 1973 Philippine Sea HHP. (10^2 cal/cm^2)

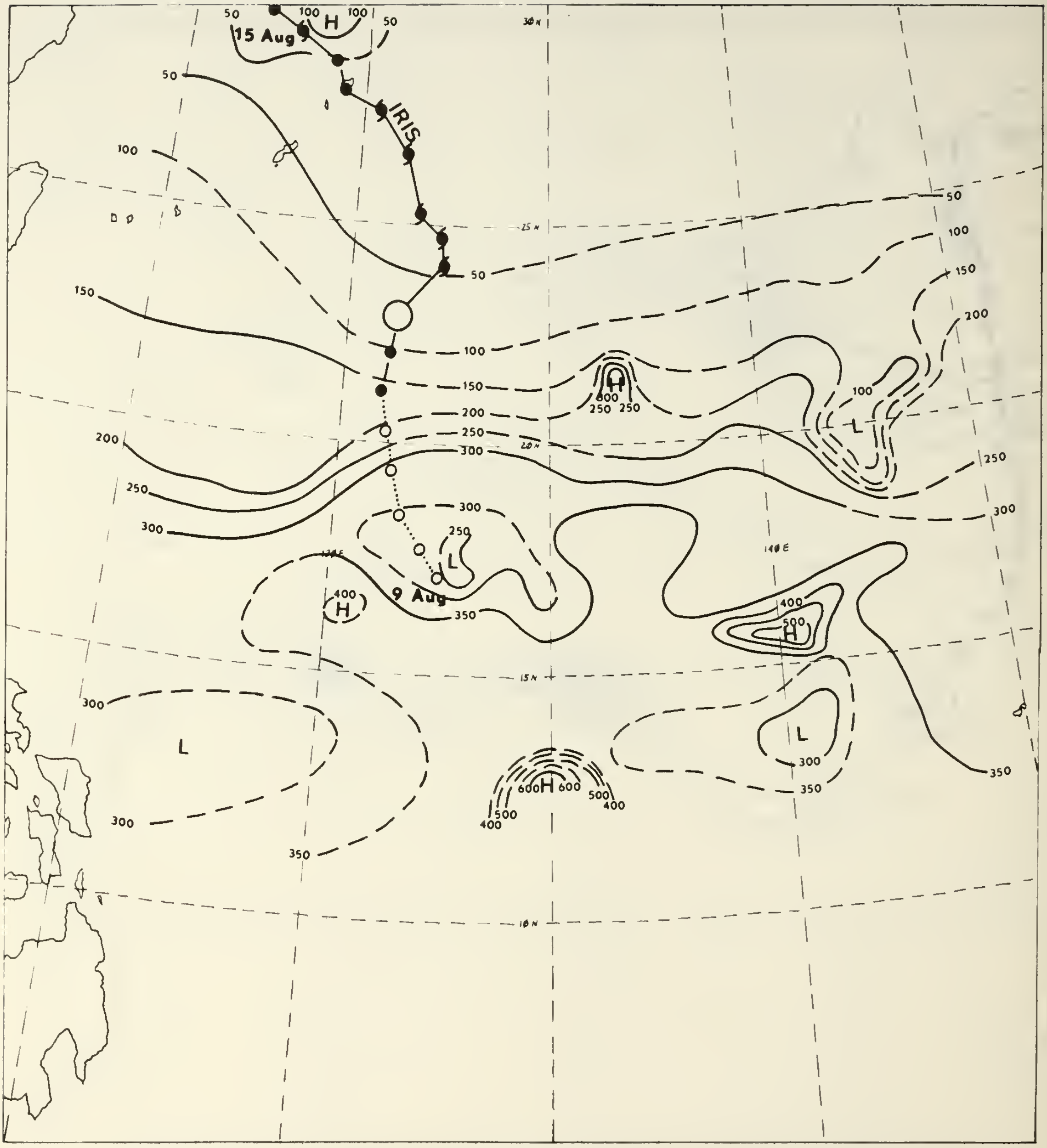

Figure 22. 1-10 August, 1973 Philippine Sea HHP. (10^2 cal/cm^2)

plotted and checked. None of them presented sufficient irregularities to be discounted; therefore they were included on the map. Their validity as representing real features is questionable. However, the 60,000 cal/cm^2-column maximum value at 135°E persists from small maxima observed in this location in June and July.

The 1-10 September map (Figure 23) indicates the beginning of the winter heat potential decrease in the Philippine Sea. The 35,000 line has retreated south of 10°N. The band of warm water between 10°N and 15°N has begun to shrink in size.

b. Seasonal changes

The heat potential in an area is determined by the processes of heating and cooling at the surface and by the character of the ocean currents. The air-ocean heat exchange processes for the Philippine Sea have been discussed briefly. In the Philippine Sea, the ocean receives heat from the atmosphere nearly all year, with the largest inputs ocurring in the summer months. This apparently was the primary factor affecting the yearly increase in heat potential.

The process of advection seemed to be less significant, but could have been a factor in the north-south shift of the HHP isolines. The north-south isoline movement corresponds to the seasonal latitudinal variations of the North Pacific Equatorial Current and the Equatorial Counter-current [Newmann 1968].

Figure 23. 1-10 September, 1973 Philippine Sea HHP.
(10^2 cal/cm^2)

To show month to month changes it is convenient to make a composite map showing the positions of one isoline (25,000) in successive months of 1973 (Figure 24). In May it had not appeared. June, July and August saw the 25,000 line appearing and moving northward (heavy lines). In September, when the water had begun to cool, the 25,000 line shows a shift to the south. Also on Figure 24 (light lines) can be seen the monthly positions of the mean 25,000 line for all available data using Heffernan [1972] results. The changes in the positions of the 25,000 isoline, while of smaller magnitude than the 1973 changes, follow the same general pattern, advancing to the north through August, then retreating south in September.

Maximum heat potential values are reached in August, historically the month of greatest typhoon frequency (Figure 2). This time of maximum is in agreement with the atlas data of Heffernan [1972], which also show heat potential maximums in August.

The 1973 ten-day maps show the development of a band of higher heat potential extending across the Philippine Sea from 10°N to 15°N. Small patches of high and low potentials also present possibly indicate a non-uniformity in the heat potential fields. The sensitivity to BT profile variations in the computation of HHP has been discussed, and the inexact recording of temperature-depth profiles may be a partial explanation for some of these small area irregularities.

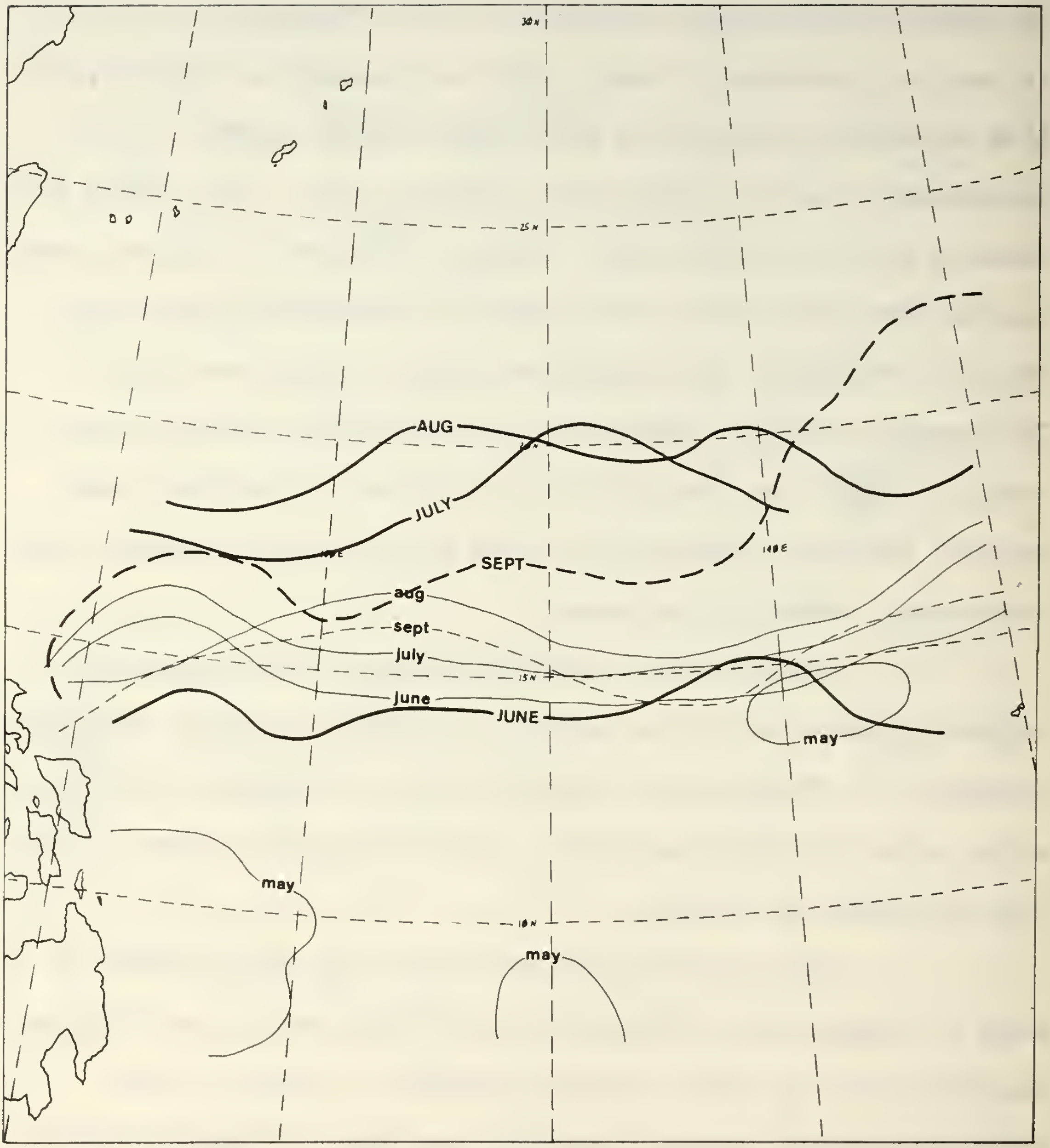

Figure 24. Composite Map of 1973 (Thick lines) Monthly Movement of 25,000 cal/cm^2 HHP Isoline. (Thin lines are monthly means).

The heat potential mean maps (Figures 25-29) were drawn using Heffernan's [1972] HHP grid values computed for 1° quadrangles of latitude and longitude. They show similar trends, a summer increase in heat potential and the formation of a warm band between 10°N and 15°N.

In the Philippine Sea the 1973 HHP values are in close agreement with the mean values, being slightly higher. The maximum mean HHP isolines do not exceed 30,000 cal/cm^2-column, while the 1973 data show a large area exceeding 35,000 cal/cm^2-column.

Difference maps were drawn for the monthly ten-day periods considered. These have an advantage in emphasizing overall trends, while small anomalous high and low value areas which appear on the monthly HHP maps are smoothed or eliminated.

In the May-June and June-July difference maps (Figures 30 and 31) large areas of positive differences are present with values greater than 15,000 cal/cm^2-column, reflecting the seasonal increase in HHP.

The July-August difference map (Figure 32) shows a more stable situation, with most differences being less than 5,000 cal/cm^2-column/month.

The August-September map (Figure 33) begins to show decreases as HHP declines from its August maximum values.

Overall the 1973 HHP maps based on the first ten days of each month correspond well with the monthly mean

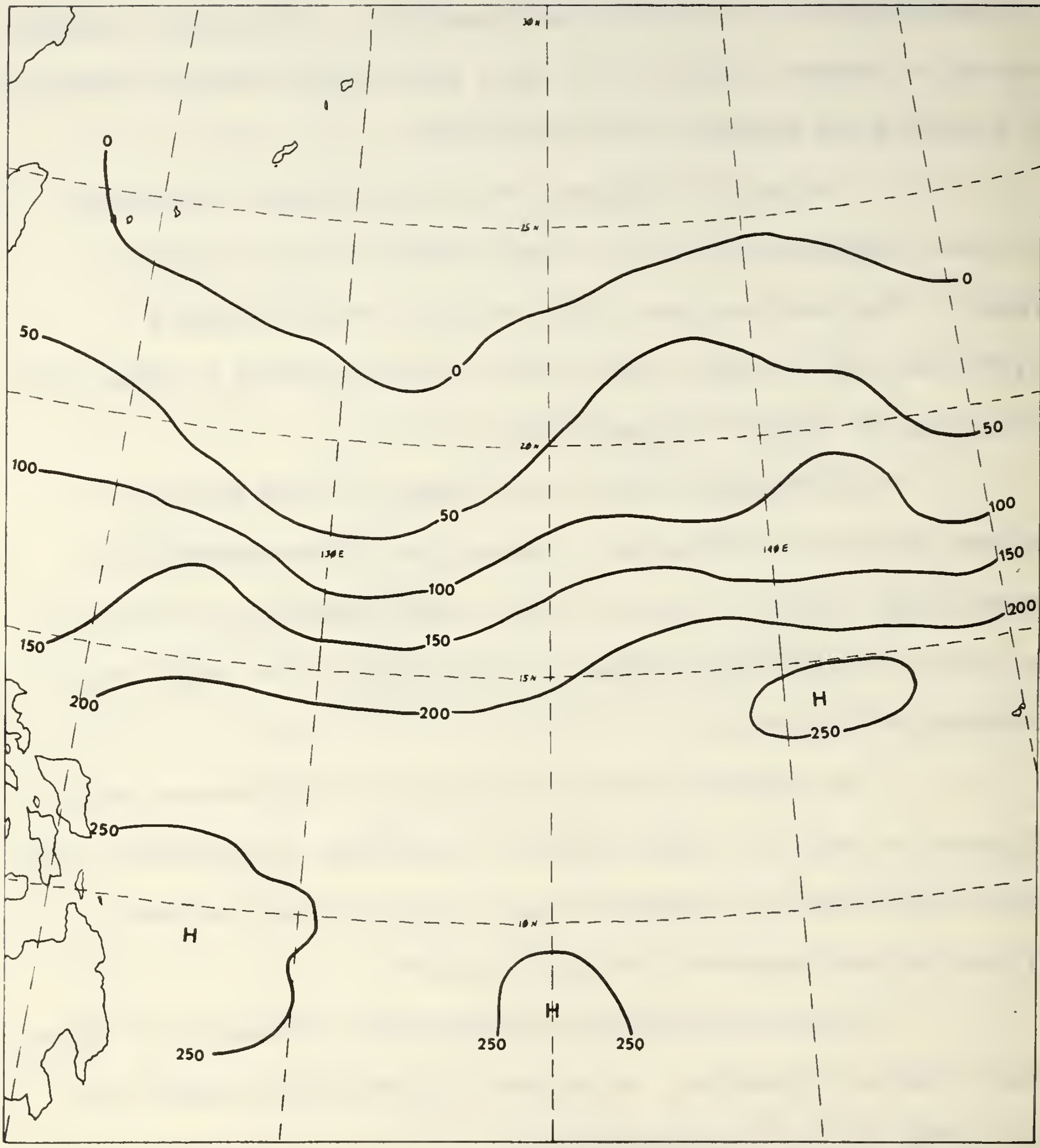

Figure 25. Philippine Sea May Mean HHP (10^2 cal/cm^2).

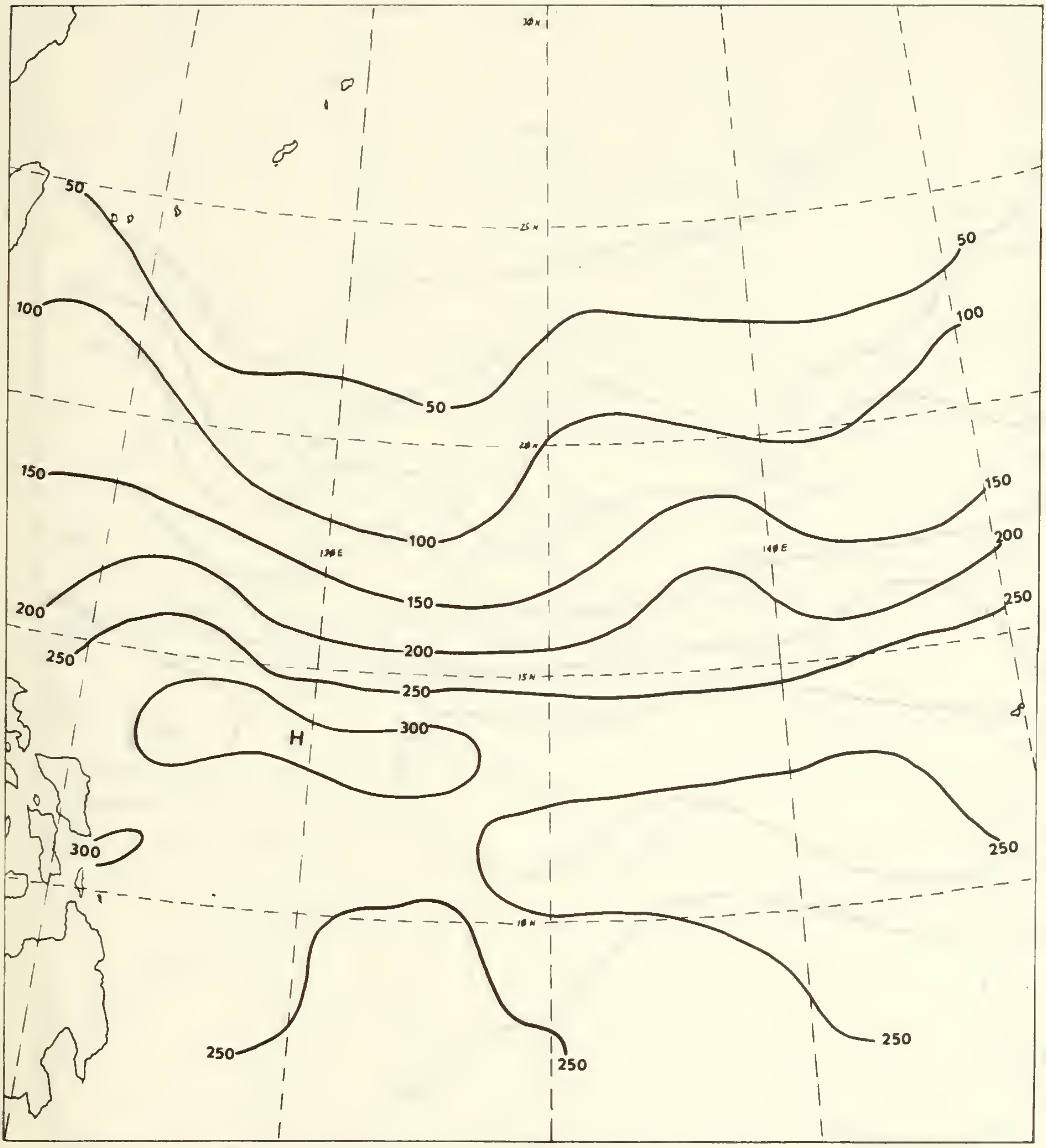

Figure 26. Philippine Sea June Mean HHP (10^2 cal/cm^2).

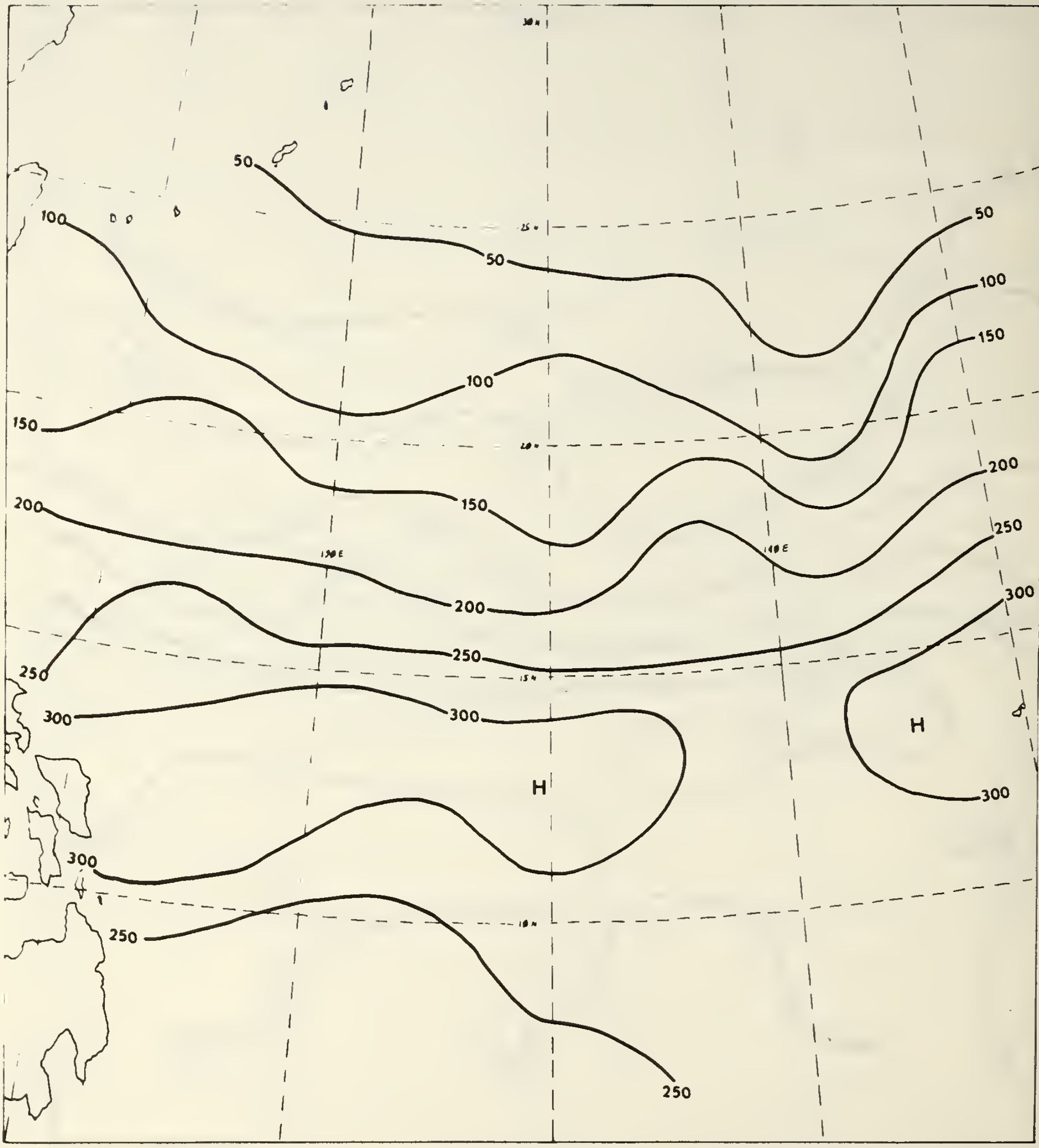

Figure 27. Philippine Sea July Mean HHP (10^2 cal/cm^2).

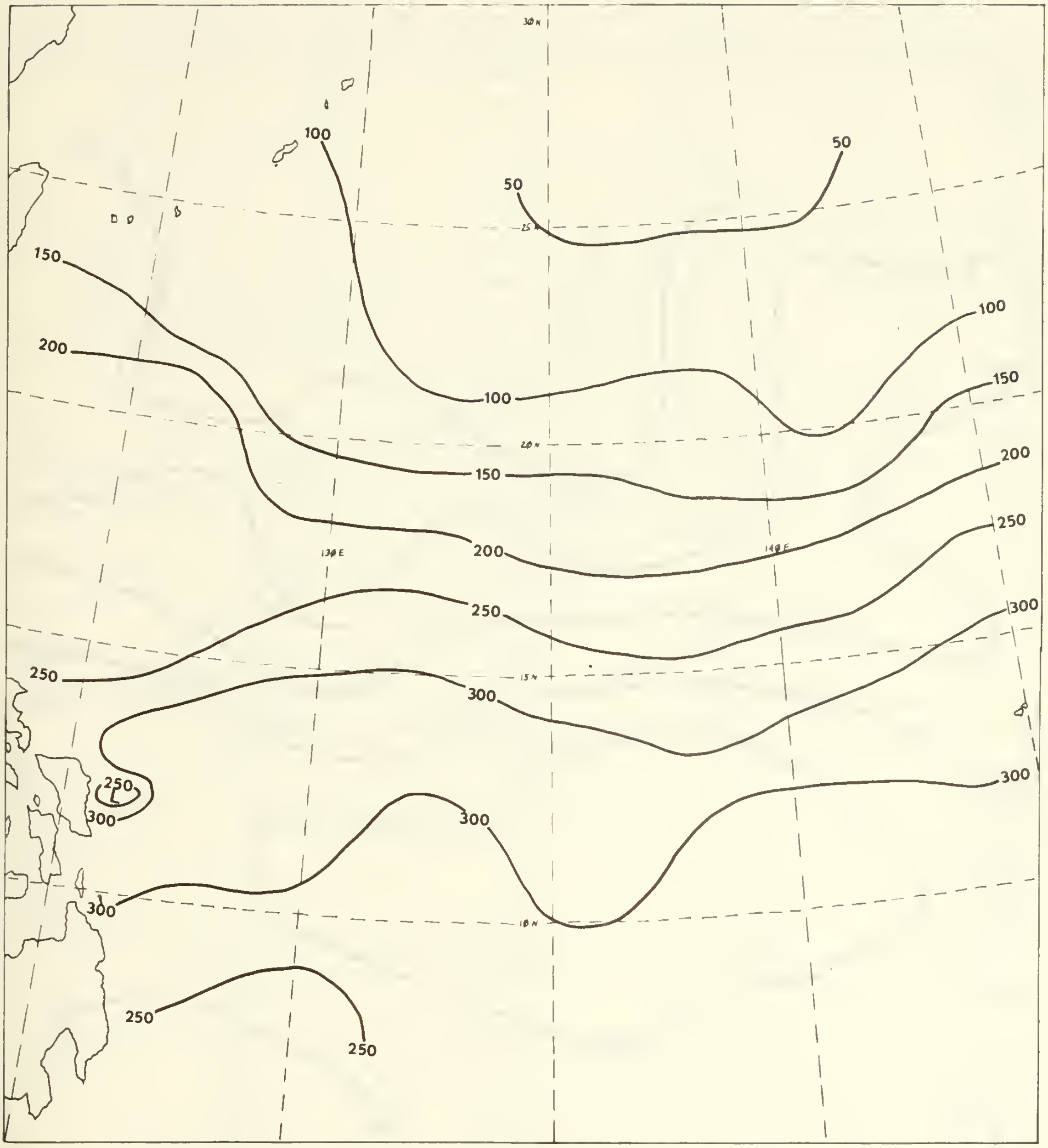

Figure 28. Philippine Sea August Mean HHP ($10^2 cal/cm^2$).

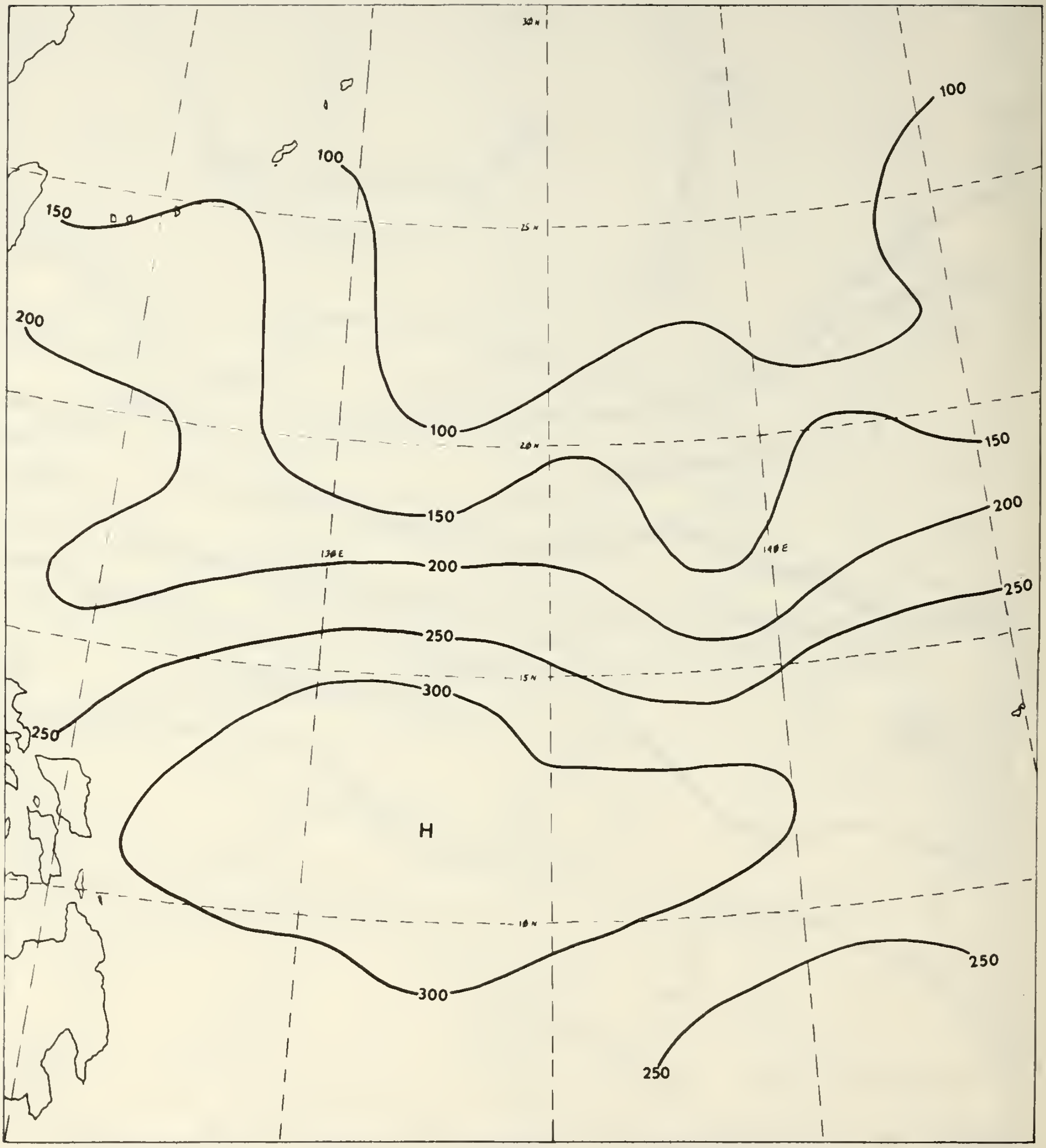

Figure 29. Philippine Sea September Mean HHP ($10^2 cal/cm^2$).

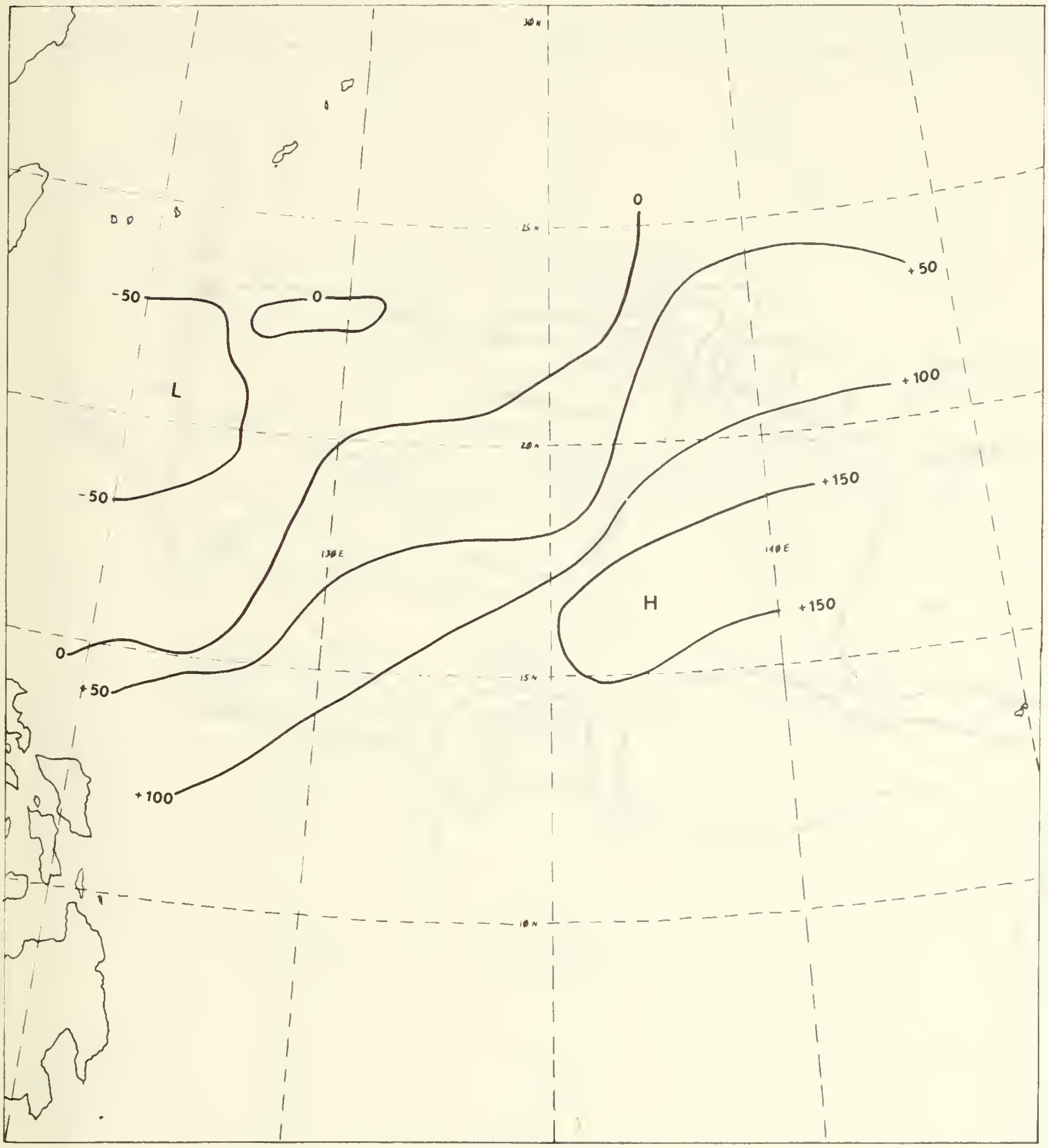

Figure 30. 1-10 May and 1-10 June HHP ($10^2 cal/cm^2$) Difference Map.

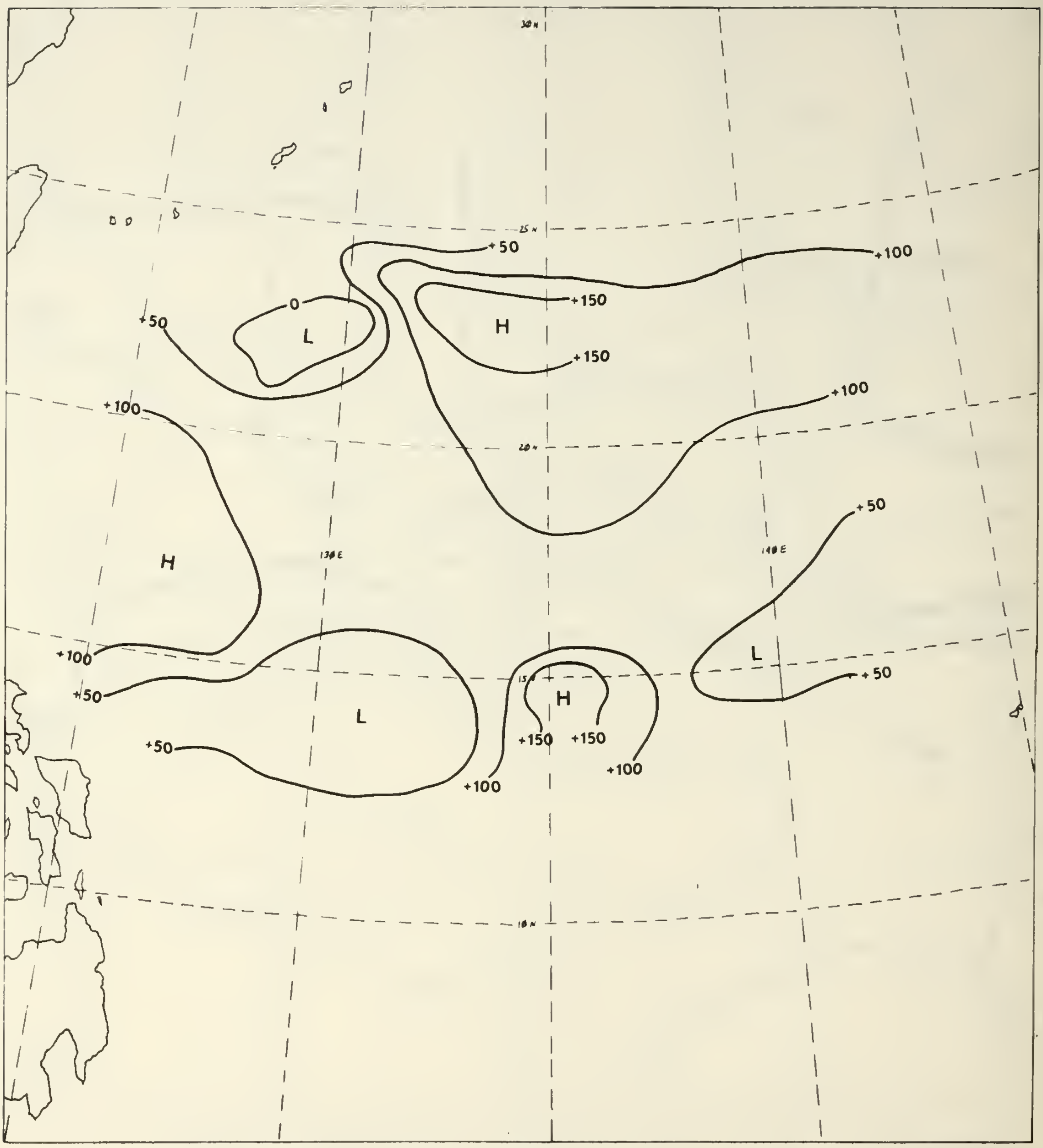

Figure 31. 1-10 June and 1-10 July HHP ($10^2 cal/cm^2$) Difference Map.

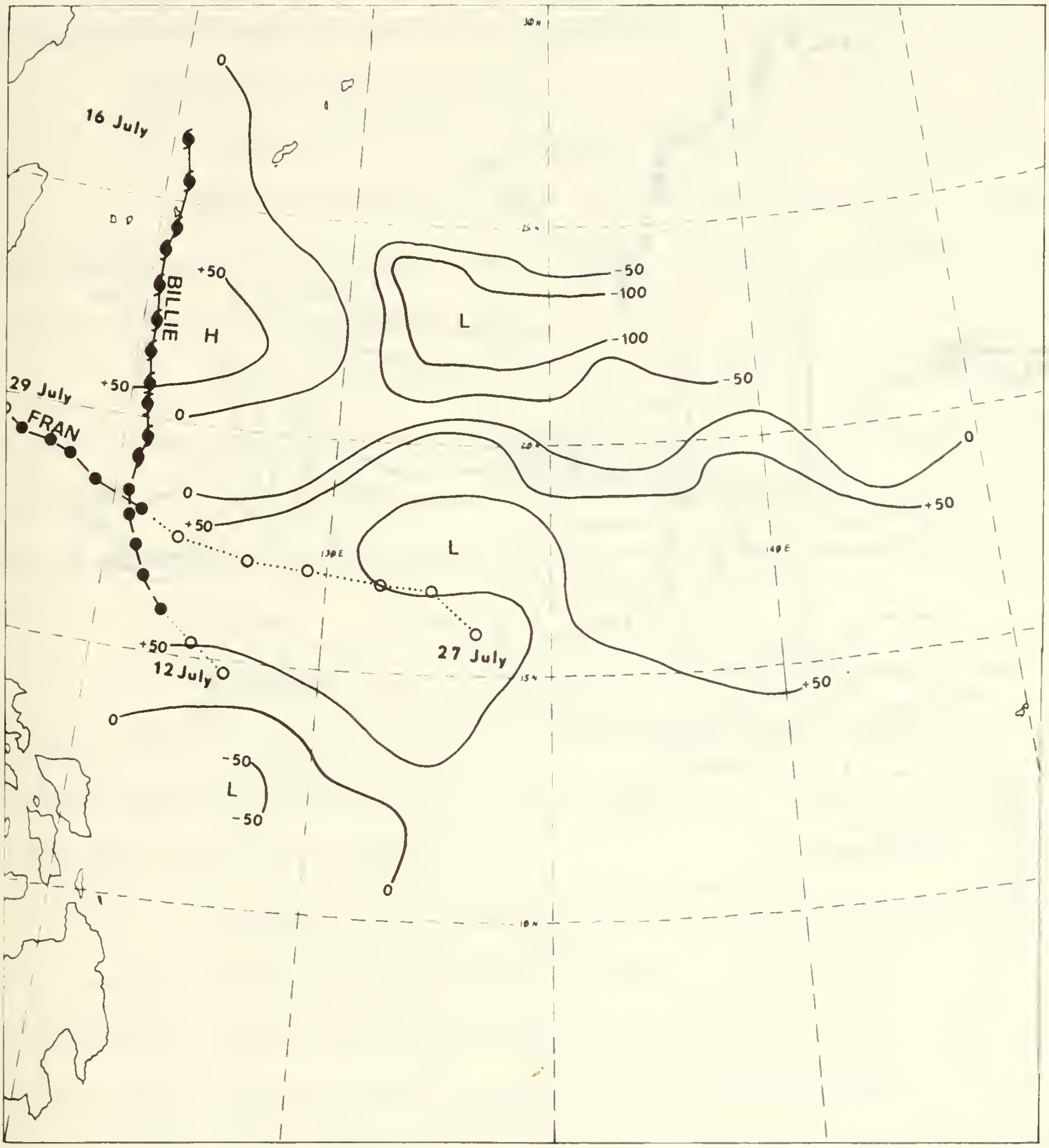

Figure 32. 1-10 July and 1-10 August HHP ($10^2 cal/cm^2$) Difference Map.

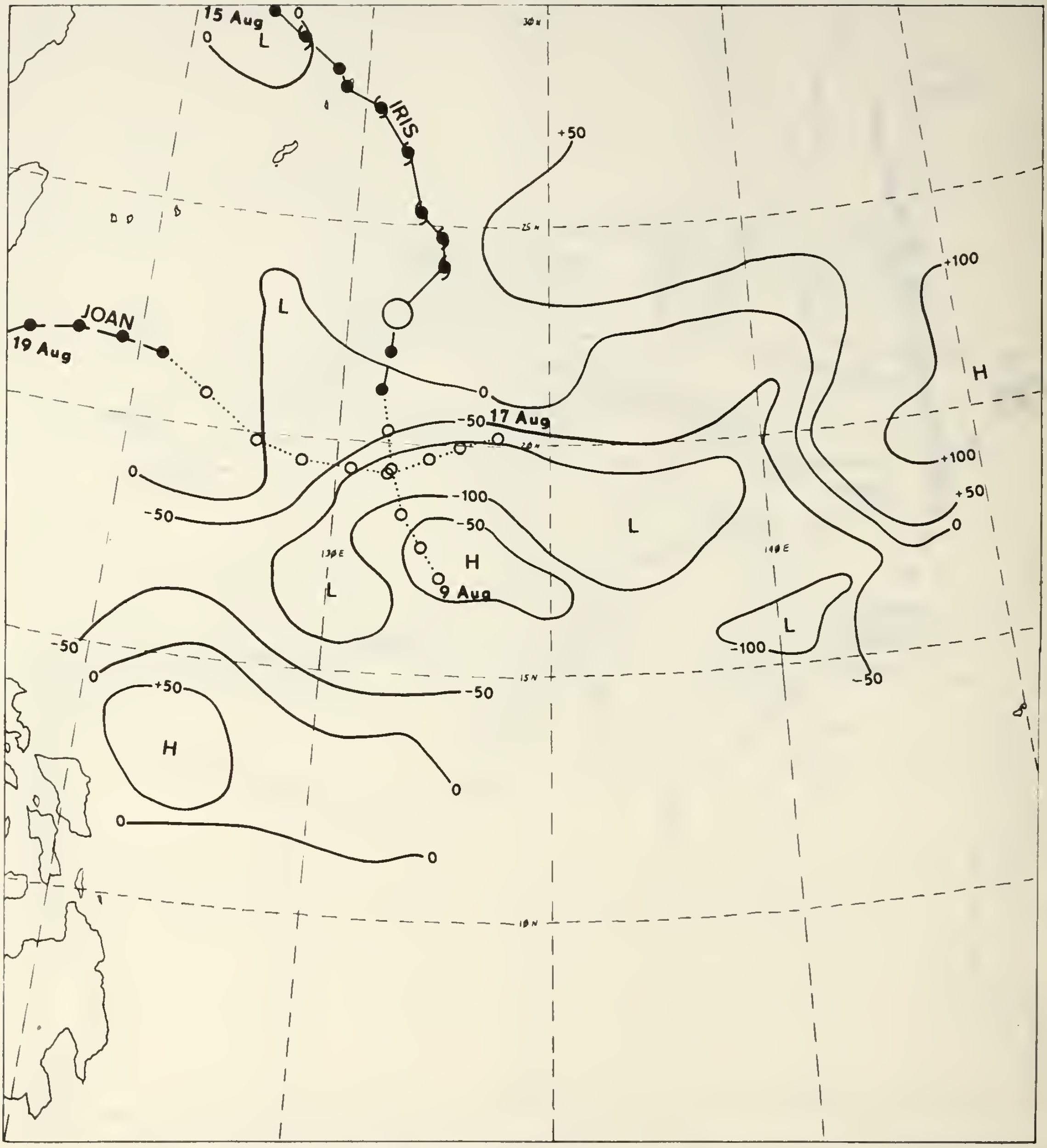

Figure 33. 1-10 August and 1-10 September HHP ($10^2 cal/cm^2$) Difference Map.

maps for all available data. Changes are more marked on the 1973 maps, and the patch-like heat potential highs and lows are not present on the mean maps.

2. Tropical Storm Activity

a. Effect of HHP on tropical storms

Two typhoons and two tropical storms were generated and passed over the Philippine Sea during the months of July-September, 1973.

Typhoon Billie formed as a tropical depression at about 15°N 127°E on 12 July (Figure 32). Building in intensity to 130 knots, she tracked north roughly along the 125°E meridian until she passed into the East China Sea and died.

Tropical Storm Fran first appeared at about 16°N 134°E on 27 July (Figure 32). Never attaining wind speeds above 40 knots, she tracked generally westward, and died just south of Taiwan.

Typhoon Iris originated as a tropical depression on 9 August (Figure 33). She tracked north to about 23°N 131°E, where she stalled and orbited for three days. On the 13th she left this position, having increased to typhoon strength, and continued on a northerly track until she left the Philippine Sea.

At about 20°N 134°E Tropical Storm Joan formed as a depression on the 17th of August. Like Fran, she tracked generally westward, and her maximum winds did not exceed 45 knots.

A survey of the average monthly typhoon tracks published by Fleet Weather Central, Pearl Harbor, Hawaii [1969] showed that the normal typhoon track limits, running east to west across the Philippine Sea, had a northerly change in position as the season progressed. From May to August, the shift along the 135°E meridion was approximately 180 n.m. The most northerly mean track limits were reached in August. This coincided with the time of HHP maximum values in the Philippine Sea. In September, the mean track paths moved to the south.

The 1973 effects of the HHP field on two tropical storms, Fran and Joan, could not be determined because of the lack of BT observations.

However, the similar tracks of typhoons Billie and Iris both entered into regions of high heat potential in the later portions of their paths. Figure 18 shows Iris entering into an area of high potential near 28°N. Typhoon Billie passed into a like area of rising heat potential on 15 July.

On 15 July at 1800 (Figure 34) Typhoon Billie's winds were decreasing as was the heat potential under her path. However, at this time she entered an area of increasing HHP and her wind speed increased corresponding to the HHP increase.

A similar phenomenon was observed with Typhoon Iris. On 15 August at 0000 hours a brief intensification

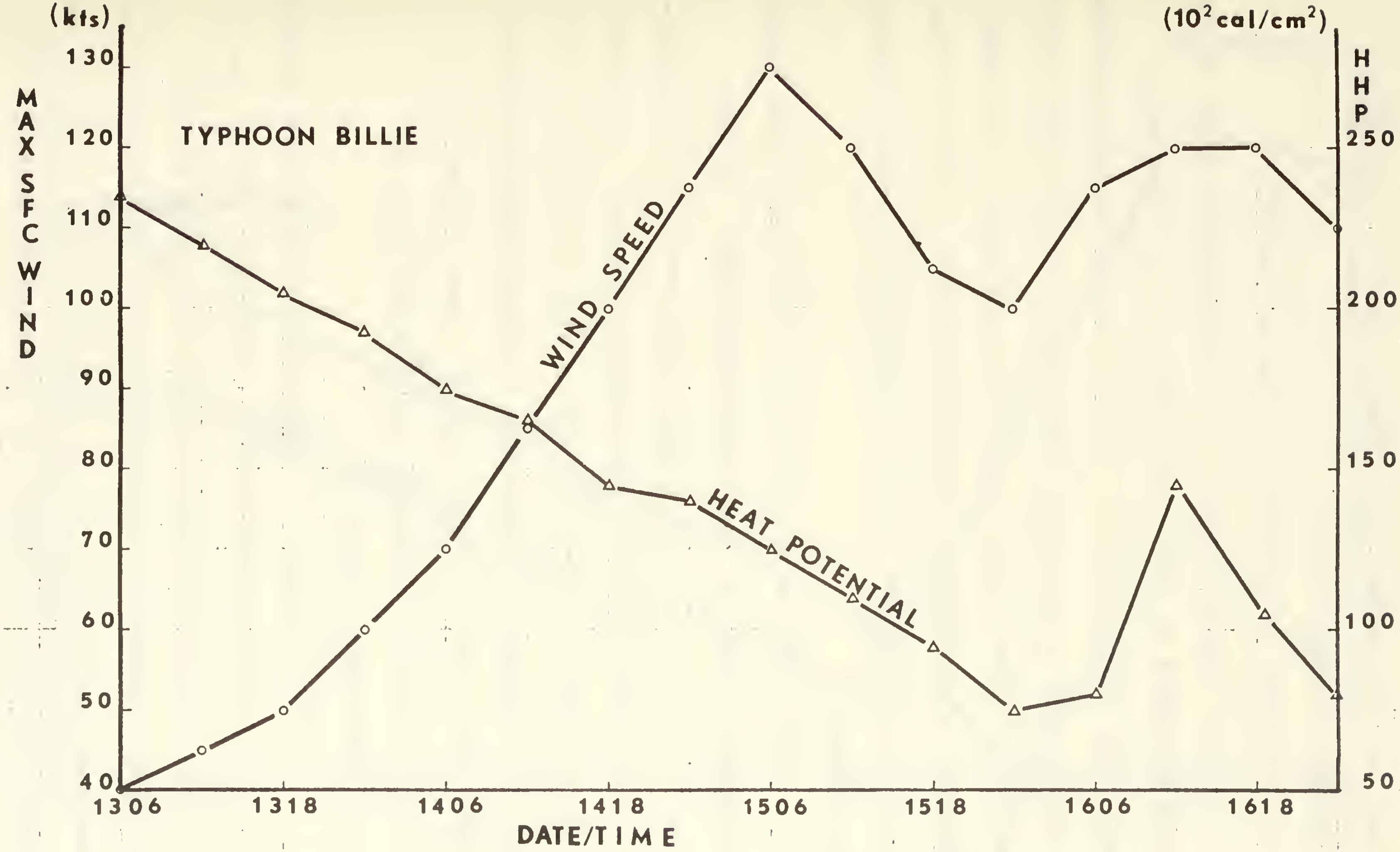

Figure 34. Correlation of Maximum Surface Wind Speed Changes to Changes in HHP During Typhoon Billie.

commenced as Iris passed over a small area of increasing heat potential (Figure 35).

b. Effect of tropical storms on the HHP

One possible effect of a tropical cyclone on the HHP field appeared in the 1-10 August to 1-10 September difference map (Figure 33). A 10,000 cal/cm^2-column decrease in HHP took place over a wide area centered about 18°N 133°E. However the difference map between the HHP means for August and September also showed a general decrease in HHP of less than 5,000 for this same period, possibly reflecting average typhoon activity.

This 1973 excess heat loss could have been caused by two factors. One, as previously mentioned, the heat potential fields peak during August, and part of the August-September heat loss reflects this seasonal trend. A second contributing factor to the abnormally high heat loss could have been the passages of Typhoons Iris and Tropical Storm Joan through the middle of the region; some extraction of heat from the sea by a tropical storm does occur, as numerous studies have stated.

The BT profiles of three observations are plotted (Figure 36). The three plotted BTs were taken within the area of 10,000 cal/cm^2-column decrease, but were several hundred miles southeast of the storm paths. Two observations were taken before Iris and Billie (Ships A and B) and one was taken after the storm (Ship C). A decrease in both HHP (36,000 and 35,900 to 22,500) and in the surface layer

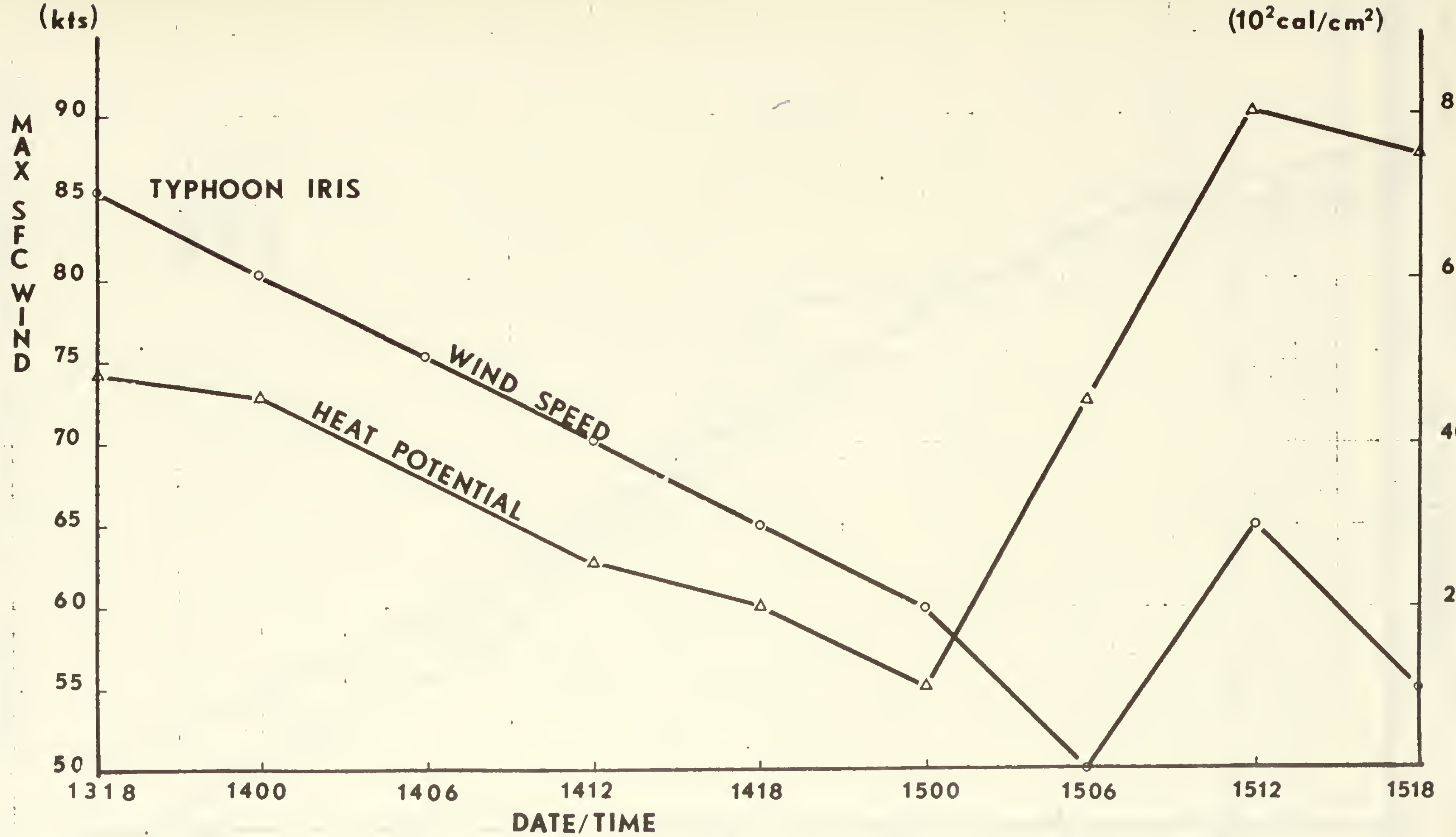

Figure 35. Correlation of Maximum Surface Wind Speed Changes to Changes in HHP During Typhoon Iris.

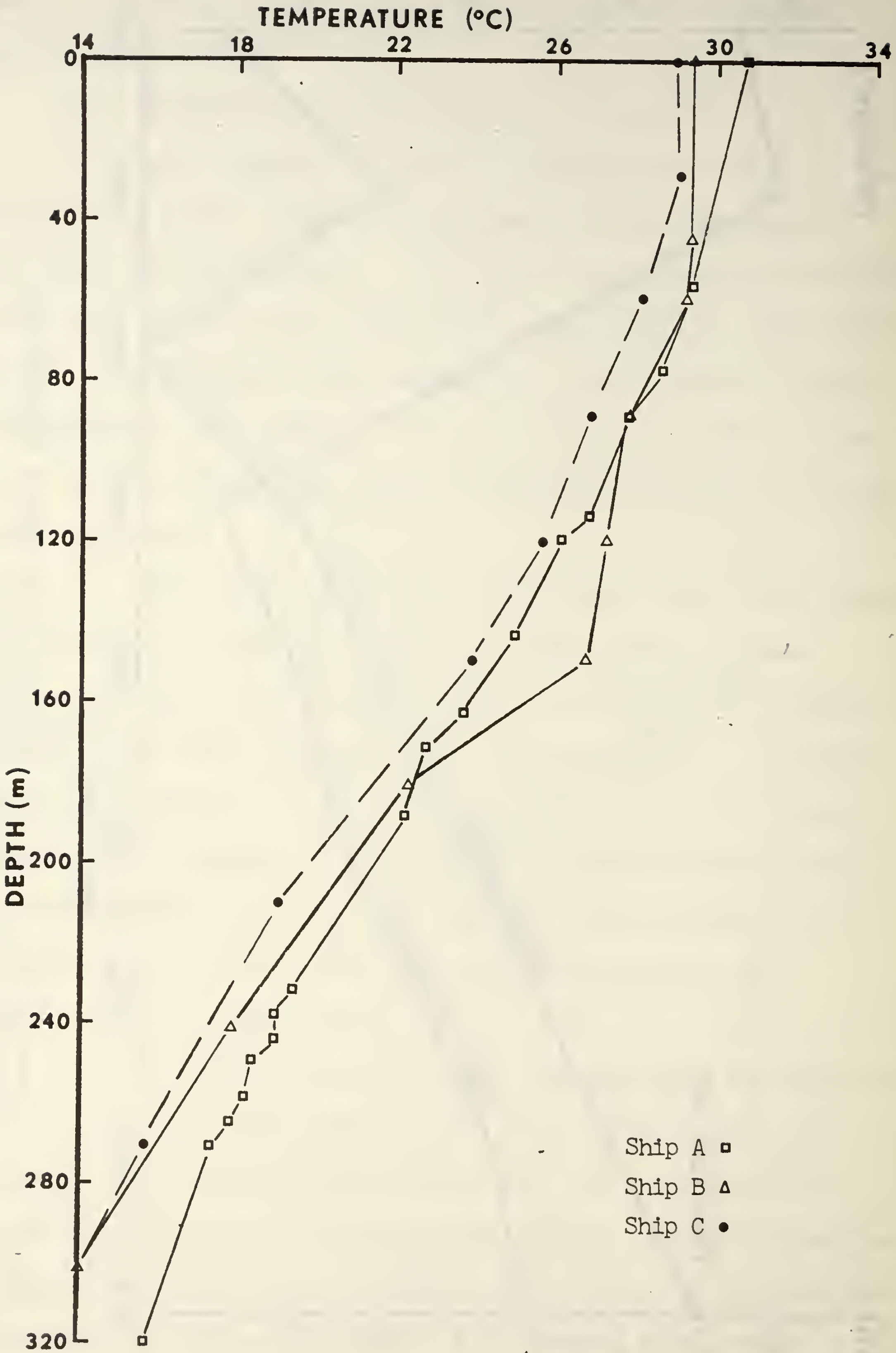

Figure 36. Comparison of Three BTs, Two Taken Before (Ships A and B), and One After (Ship C) Storm Passages Over an Ocean Area.

temperature is observed. The normal deepening of the mixed layer following a storm did not occur. Instead, the mixed layer decreased, an indication of upwelling.

However no BTs were available both before and after the storms from the exact positions over which the two storms passed.

V. CONCLUSIONS

1. There was a much better data base of 1973 BT observations both in number and in extent of coverage for the Philippine Sea than in the Gulf of Mexico, but both areas showed a deficiency in BT observations in areas and times of highest interest to HHP studies (in proximity to storms). To define properly the interrelationships between HHP and tropical storms, a regular, repetitive ocean sampling program must be pursued and monitored, such as that proposed for Project OSTroC.

2. A practical computer method for computing and plotting HHP values by location from operational BTs was carried out successfully. HHP contour maps were then drawn for ten-day or monthly periods in the 1973 hurricane/typhoon season in the Gulf of Mexico and the Philippine Sea.

3. There exists a need for a more reliable system of observations in order to distinguish true variability in HHP from artificial variability created by incorrect observational data.

4. Seasonal variations in HHP in the Philippine Sea in 1973 were observed as the north-south movement of east-west bands. HHP maximum values were imbedded in a warm belt extending longitudinally across the Philippine Sea from 10°N to 15°N.

The outstanding seasonal feature in 1973 of HHP in the Gulf of Mexico was a warm water intrusion progressing

from the Yucatan Channel into the interior Gulf. HHP maximums were included in the loop and eddy related to this tongue.

5. The two months of maximum northward extent of HHP in the Philippine Sea, August and September, coincided with the months of maximum climatological typhoon activity. The 1973 storms were distributed evenly throughout the season, with two storms occurring in July, two in August, and three in October.

In the Gulf of Mexico, the month of maximum HHP occurred in August, which in 1973 was also the month of maximum hurricane activity.

6. The atlas maximum HHP values of Heffernan [1972] were approximately half those found in the Gulf of Mexico in 1973, probably because of the variability of ocean currents in the Gulf. However, 1973 August Gulf HHP values were in good agreement with the HHP fields computed by Volgenau and Leipper [1972] for the August 1965-1968 periods. Maximum HHP values in the Gulf for these five individual years ranged from 20,000 to 35,000 cal/cm^2-column. Locations of the centers differed from year to year.

The 1973 Philippine Sea HHPs agreed well (within 5000 calories) with the Heffernan atlas values. In 1973, large area maximums of greater than 35,000 cal, but less than 40,000 cal, were present.

HHP maximums in 1973 were greater both in geographical extent and in quantity in the Philippine Sea than in the Gulf of Mexico.

7. The correlations between a) the HHP fields in 1973 and 1965-68 in the Gulf of Mexico and b) the tracks and intensities of the tropical storms and hurricanes occurring in those years were inconclusive. Sufficient correspondence of the direct influence of HHP on storm behavior was present to merit further investigations of this type.

8. In 1973 two instances occurred in the Philippine Sea where tropical cyclones passing over an area of higher HHP experienced an increase in maximum surface winds. The passages of typhoons Iris and Billie into areas of higher heat potential resulted in an increase in the maximum wind speed of 15 and 20 knots, respectively. This suggested a correlation between changes in HHP along the cyclone path and tropical cyclone intensity changes.

9. An abnormally high monthly heat loss of 10,000 calories occurred when two tropical storms passed over a broad area of the Philippine Sea, reflecting the capacity of tropical storms to remove heat from the ocean.

VI. RECOMMENDATIONS

1. Initiate an expanded sampling program to improve synoptic HHP coverage.

2. Expand the HHP plot program to include the processing of real time observations, permitting use of ocean environmental parameters as factors in the forecasting of hurricane behavior.

3. Study the question of what influence HHP has on tropical cyclone tracks and intensities.

4. Study the BT information and the HHP in the Philippine Sea in the 1972 season. Project OSTroC briefings had been given to operational units that spring, and in the summer of 1972 Project OSTroC sampling efforts probably were attempted.

5. Investiage how HHP relates to the Eastern North Pacific Ocean and to the hurricanes passing through that region.

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APPENDIX A

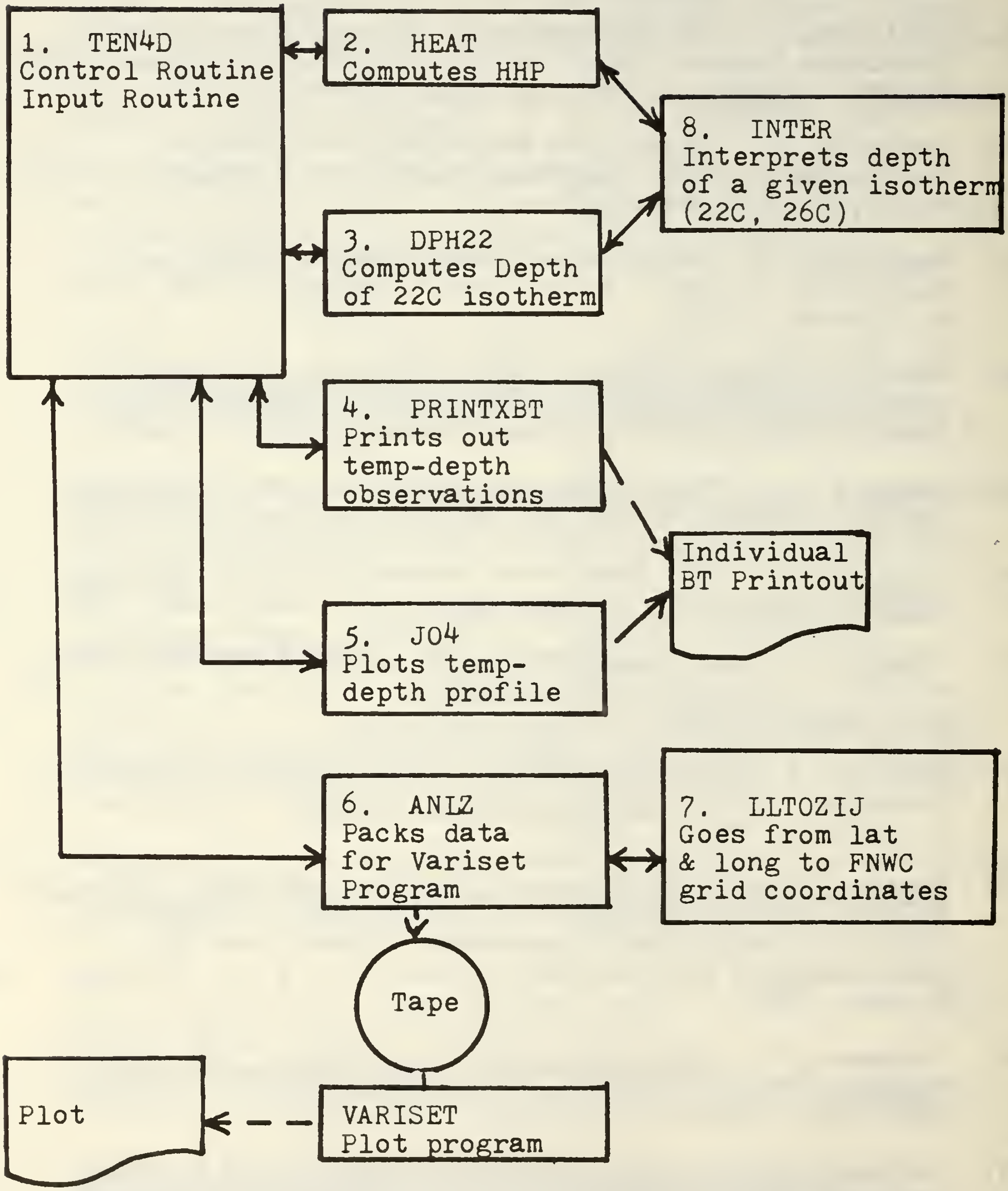


Figure 37. HHP Program Flow Chart.

```
VESSEL   DAY  MONTH  YEAR  TIME(GCT)  LATITUDE  LONGITUDE  BASELINE TEMP
 XKBNA     1  MAY     73    1130       22-25N    86-16W        27.00

OCTANT  CLASS  TYPE
  0             D
DEPTH   TEMP  DEPTH  TEMP  DEPTH  TEMP  DEPTH  TEMP  DEPTH  TEMP  DEPTH  TEMP  DEPTH  TEMP  DEPTH  TEMP
    0  27.00     49  27.0     61  26.78   119  23.00   149  21.61   229  17.50   287  16.00   299  15.11
  351  14.00    390  13.50   399  12.50   485  10.89   518  10.61

    POTENTIAL HEAT =        64      D22 =      141
```

GRAPHIC DISPLAY OF TEMPERATURE WITH DEPTH

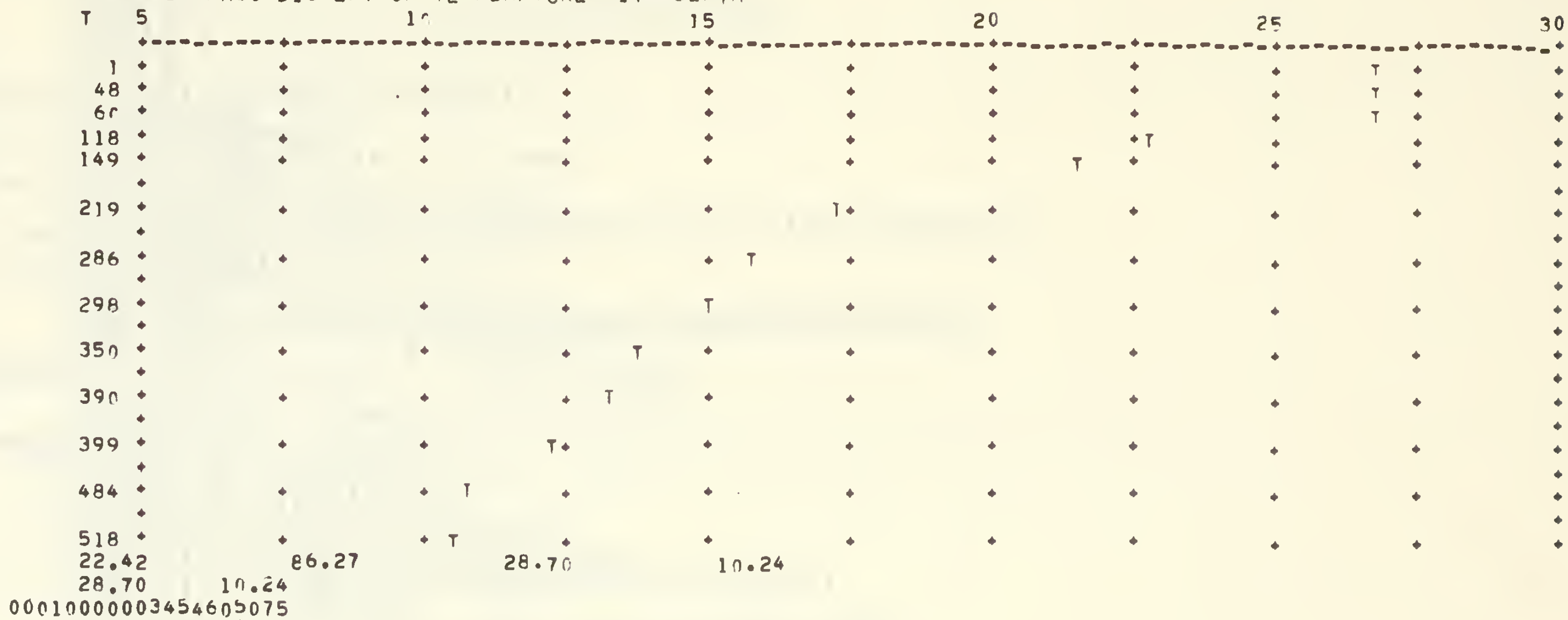


Figure 38. Sample Output of Single BT Observation.

APPENDIX A

```
C      THIS PROGRAM COMPUTES THE HURRICANE HEAT POTENTIAL
C      AND THE DEPTH OF THE 22C ISOTHERM UTILIZING THE FNWC
C      CDC 6500 COMPUTER.
       PROGRAM TEN4D(INPUT,OUTPUT,TAPE1=INPUT,TAPE2)
       DIMENSION FORM(40)
       DIMENSION XLAT(24),XLON(24),K(12),KNT(12)
       DIMENSION DEPTH(100),TEMP(100)
       DIMENSION IDPTH(6),ITEMP(6)
       DIMENSION D(21),LA(26)
       DIMENSION TITLE(4)
       COMMON/AAK/ IX,DATA(250)
COMMENT.  *   *   *   *   *
C      PROGRAM BY K. RABE
C      JULY 1973
COMMENT.  *   *   *   *   *
       LSHIP=8H          $ JTYPE=1H
       IDAY=IMO=IYR=IOCT=LAT=LATM=LON=LONM=IHOUR=NSET=0
       READ 871, (TITLE(I),I=1,4)
  871  FORMAT(4A10)
       PRINT 779,(TITLE(I),I=1,4)
  779  FORMAT(1H1,//////////,20(X,5H*****),//,10X,4A10,//)
       READ 1061,(FORM(I),I=1,40)
 1061  FORMAT(8A10)
       PRINT 1062,(FORM(I),I=1,40)
 1062  FORMAT(10X,8A10)
       PRINT 1063
 1063  FORMAT(///,20(X,5H*****))
       IX = 1
       KSET = 0
       KOUNT=0
       INEXT=0
       ISTOP=0
  530  CONTINUE
       READ (1,20) (D(I),I=1,12)
   20  FORMAT(A8,A8,2A6,2A8,6A6)
       IF(EOF,1) 199,85
  199  ISTOP=1
       IF(IT.LE.0) GO TO 776
       GO TO 500
   85  DECODE(10,29,D(1))LA(26)
   29  FORMAT(A8,2X)
   25  DECODE(110,26,D(2))(LA(I),I=1,25)
   26  FORMAT(A1,3I2,3X,I1,2I2,5X,I3,I2,5X,I4,1X,I3,2X,2(1X,I3),2X,6(1X,
      1I2,I3,4X))
       IF(KSET.EQ.0) GO TO 101
```

```
150 IF(LA(26).NE.LSHIP.OR.LA(1).NE.JTYPE.OR.LA(2).NE.IDAY.OR.LA(3).NE.
   1IMO.OR.LA(4).NE.IYR.OR.LA(5).NE.ICCT.OR.LA(6).NE.LAT.OR.LA(7).NE.
   2LATM.OR.LA(8).NE.LON.OR.LA(9).NE.LONM.OR.LA(10).NE.IHOUR)151,10
101 CONTINUE
    KSET = 1
    INEXT=0
    LSHIP=LA(26)  $  IHOUR=LA(10)
    ICCT=LA(5)  $  IDAY=LA(2)  $ IMO=LA(3)  $  IYR=LA(4)
    JTYPE=LA(1)  $  ISST=LA(13)
    LAT=LA(6)  $  LATM=LA(7)
    LON=LA(8)  $  LONM=LA(9)
    ALON=LON+LONM/60.
    ALAT=LAT+LATM/60.
    IF(IOCT.GE.4)ALAT=-ALAT
    IF(IOCT.EQ.0.OR.IOCT.EQ.1)ALON=-ALON
    IF(IOCT.EQ.5.OR.IOCT.EQ.6)ALON=-ALON
    LATS = 1RN
    IF(ALAT.LT.0.0) LATS = 1RS
    LONGS = 1RE
    IF(ALON.LT.0.0) LONGS = 1RW
    LONS = LONGS
    IT = 1
    IFACT = 0
    DEPTH(IT) = 0.0
    TEMP(IT) = FLOAT(ISST)/10.0
 10 CONTINUE
    DO 300 JJ = 14,24,2
    IT = IT +1
    IF(LA(JJ).EQ.99.AND.LA(JJ+1).GT.900) GO TO 400
    IJ = JJ/2
    IF(D(IJ).EQ.6H      ) GO TO 500
    DEPTH(IT) = (LA(JJ)*10) + IFACT
    TEMP(IT) = FLOAT(LA(JJ+1))/10.0
    GO TO 300
400 IFACT = (LA(JJ+1)-900) * 1000
    IT=IT-1
300 CONTINUE
    GO TO 530
C
C  PROFILE NOW COMPLETE
151 CONTINUE
    INEXT=1
    IT = IT +1
500 CONTINUE
    IT = IT -1
```

APPENDIX A (CCN'T)

```
      DC 600 I = 1,IT
      TEMP(I) = (TEMP(I)-32.0)*(5.C/9.0)
      DEPTH(I) = DEPTH(I)/3.28
  60C CCNTINUE
      CALL HEAT(DEPTH,TEMP,PHT,IT)
      CALL DPH22(DEPTH,TEMP,D22,IT)
      NCLAS = 2H
      BTEM = TEMP(1)
      CALL PRNTXBT(DEPTH,TEMP,IT,LSHIP,IYR,IMO,IDAY,IHOUR,LAT,
     1LATM,LATS,LON,LONM,LONS,BTEM,IOCT,NCLAS,JTYPE)
      PRINT 775,PHT,D22
  775 FCRMAT(//,5X,* POTENTIAL HEAT = *,F10.0,5X,*D22 = *,F7.0)
      CALL J04 (DEPTH,TEMP,1,IT,NLAT,NLONG,NLATH,NLONH)
      CALL ANLZ( PHT,LAT,LON,LATM,LONM,LATS,LONGS)
      IFACT = 0
      IT=0
      IF(ISTOP.EQ.1) STOP77
      IF(INEXT.EQ.1) GO TO 101
      KSET = 0
      IF(ISTOP.NE.1) GO TO 530
  776 CONTINUE
      IX = IX +1
      DATA(IX) = 0.0
      BUFFEROUT(2,1) (DATA(1),DATA(IX))
      STOP11
      END
```

```
      SUBROUTINE J04 (DEP   ,TEMP,KE,KEP,NLAT,NLONG,NLATH,NLONH)
      DIMENSION LINE(100),DEP(100),TEMP(100)
C F04 PRINTING OF VALUES
   42 FORMAT  (25X,5HDEPTH,6X,5HTEMP.,6X,6HSALIN.,6X,6HVELOC./)
   43 FORMAT  (25X,F5.0,6X,F5.2,6X,F5.2,6X,F7.2)
   50 FORMAT  (///,20X,55H GRAPHIC DISPLAY OF TEMPERATURE WITH DEPTH
     1                          ,)
  251 FORMAT(25X,4HLAT.,F7.1,A2,4X,5HLONG.,F7.1,A2,/)
  253 FORMAT(1H1,25X,4HDATE,   I6,   4X,I6,///)
      KKE=KE
C     GRAPHING OF VALUES
  261 FORMAT(15X,1HT,3X,1H5,18X,2H10,18X,2H15,18X,2H20,18X,2H25,18X,2H30
     1)
      PRINT 50
      PRINT 261
      IT=1HT
      IS=1HS
      IV=1HV
      IX=1HX
      IY=1HY
      IBLANK=1H
      IP=1H+
      IM=1H-
      IZ=1HZ
      DO 64 I=1,100
   64 LINE(I)=IM
      DO 66 I=10,100,10
   66 LINE(I)=IP
      PRINT 113,(LINE(I),I=1,100)
  113 FORMAT(19X,1H+,100A1)
      DO 68 I=1,99
   68 LINE(I)=IBLANK
   71 I=KE
      IF(DEP(I)-150.)75,75,72
   72 DEUI=DEP(I)-DEP(I-1)
      IF(DEP(I)-1500.)730,730,720
  720 KL=XFIXF(DEUI/100.)
      GO TO 740
  730 KL=XFIXF(DEUI/50.)
  740 KAK=1
   73 PRINT 200,(LINE(L),L=1,99)
  200 FORMAT(19X,1H+,99A1,1H+)
      IF(KAK-KL)74,75,75
   74 KAK=KAK+1
      GO TO 73
```

```
C      CONTINUATION OF SUBROUTINE J04
C      TEMPERATURE
    75 DO 210  L=10,100,10
  210  LINE(L)=IP
       J=XFIXF(TEMP(I)*4.)-20
       IF(J)82,82,83
    82 J=1
    83 IF(J-100)85,84,84
    84 J=99
    85 LINE(J)=IT
       IF(DEP(I))400,400,114
   400 DEP(I)=1.
   114 IDEP=XFIXF(DEP(I))
       PRINT 310,IDEP,(LINE(I),I=1,99)
   310 FORMAT(10X,I8,1X,1H+,99A1,1H+)
       DO 333  I=1,99
   333 LINE(I)=IBLANK
       KE=KE+1
       IF(KE-KEP)71,71,345
   345 KE=KKE
       RETURN
       END
```

APPENDIX A (CON'T)

```
      SUBROUTINE LLTOZIJ(YLAT,XLONG,XI,XJ)
      DATA(IBADIE=1)
      XLAT=YLAT $ YLONG=XLONG
      IF(XLAT)3,5,5
C     SOUTHERN HEMISPHERE
 3    IF(XLAT+30.)90,9,9
 5    IF(XLAT-90.)9,9,90
 9    IF(YLONG)30,30,20
C     EAST LONGITUDE
 20   IF(YLONG-10.)30,22,22
 22   YLONG=-(360.-YLONG)
 30   YLG= (350.+YLONG)*.017450
      XLAT= XLAT *.017450
      CONST=62.410*(COS (XLAT)/(1.0 + SIN(XLAT)))
      XI=62.0 + CONST * COS(YLG)
      XJ=62.0 + CONST * SIN(YLG)
 31   RETURN
 90   IF(IBADIE)999,900,999
  900 PRINT 1,YLAT,YLONG
 1    FORMAT(10X, 12HBAD LAT LONG,2X, 2F10.4)
 999  XI=-990.
      GO TO 31
      END
```

```
      SUBROUTINE PRNTXBT(DPTH,TMP,N,ISHIP,IYR,IMO,IDAY,IHOUR,LATD,
     1LATM,LATS,LONGD,LONGM,LONGS,BTEM,IOCT,NCLAS,JTYPE)
      DIMENSION MO(12)
      DIMENSION DPTH(100),TMP(100),IDTG(5)
      MO(1)=3RJAN $MO(2)=3RFEB $MO(3)=3RMAR $MO(4)=3RAPR
      MO(5)=3RMAY $MO(6)=3RJUN $MO(7)=3RJUL $MO(8)=3RAUG
      MO(9)=3RSEP $MO(10)=3ROCT $MO%(1)=3RNOV $MO(12)=3RDEC
  102 FORMAT(/,/,72H VESSEL  DAY  MONTH  YEAR  TIME(GCT)  LATITUDE  LONG
     1ITUDE  BASELINE TEMP)
  103 FORMAT(2X,A8,1X,I2,2X,R3,3X,I4,4X,I2,I2,6X,I2,1H-,I2,R1,4X,I3,
     11H-,I2,R1,7X,F5.2,/)
  104 FORMAT(X,8(14HDEPTH   TEMP  ))
  105 FORMAT(X,8(F5.0,2X,F5.2,2X))
  196 FORMAT(/,* OCTANT  CLASS   TYPE*)
  197 FORMAT(2X,I5,2(3X,A4))
      PRINT 1091
 1091 FORMAT(1H1,//)
      IDTG(2)=IMO
      IDTG(3)=IDAY
      IDTG(1)=IYR
      IDTG(4)=IHOUR/100
      IDTG(5)=MOD(IHOUR,100)
      PRINT 102
      M=IDTG(2)
      PRINT 103,ISHIP,IDTG(3),MO(M),IDTG(1),IDTG(4),IDTG(5),LATD,LATM,
     1LATS,LONGD,LONGM,LONGS,BTEM
      PRINT 196
      PRINT 197, IOCT,NCLAS,JTYPE
      PRINT 104
      PRINT 105,(DPTH(I),TMP(I),I=1,N)
      RETURN
      END
```

APPENDIX A (CON'T)

```
      SUBROUTINE HEAT(D,T,PHT,IT)
      DIMENSION D(100),T(100)
C
C     SUBROUTINE COMPUTES THE HURRICANE HEAT POTENTIAL
C
      PHT=0.0
      IF(T(1).LE.26.0) GO TO 300
      DO 100 I=2,IT
      IF(T(I).LT.26.0) GO TO 200
      D1=T(I)-26.0
      D2=T(I-1)-26.0
      AD = ((D1+D2)/2.0) *(D(I)-D(I-1))
      PHT=PHT+AD
  100 CONTINUE
  200 CONTINUE
      IF(T(I-1).EQ.26.0) GO TO 300
      CALL INTER(D(I),D(I-1),T(I),T(I-1),AD,26.0)
      PHT = PHT + AD
  300 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE DPH22 (D,T,D22,IT)
      DIMENSION D(100),T(100)
C
C     SUBROUTINE COMPUTES THE DEPTH OF THE 22 DEGREE ISOTHERM
C
      DO 100 I = 1,IT
      IF(T(I).LT.22.0) GO TO 300
  100 CONTINUE
  300 CONTINUE
      IF(T(I-1).EQ.22.0) D22=D(I)-1
      IF(T(I-1).EQ.22.0) GO TO 500
      CALL INTER(D(I),D(I-1),T(I),T(I-1),D22,22.0)
  500 RETURN
      END
```

```
      SLBROUTINE ANLZ(DAT,LAT,LON,LTM,LGM,LTS,LGS)
C
C   SLBROUTINE TO CONVERT HURRICANE HEAT POTENTIAL DATA INTO ANALZ FCRMAT
C   FCR LSE BY THE VARISET PLOT PACKAGE
C
      CCMMON/AAK/ IX,DATA(250)
      REAL IBUF
      IBUF = 0.0
      XTM = FLOAT(LTM)/60.0
      XGM = FLOAT(LGM)/60.0
      XLAT=FLCAT(LAT)+XTM
      XLONG=FLOAT(LON)+XGM
      IF(LTS.EQ.1HS)XLAT=-XLAT
      IF(LGS.EQ.1HE) XLONG = -XLONG
      CALL LLTOZIJ(XLAT,XLONG,XI,XJ)
      XI = XI/2.0
      XJ = XJ/2.0
      IA=0
      IB=0
      PRINT 400,XLAT,XLONG,XI,XJ
 1400 FORMAT(10X,2F10.2)
  400 FCRMAT (10X,4(F10.2,5X))
C NOW HAVE LOCATION IN REAL I,J
C NOW HAVE INTEGER I,J IN INTEGERS AND FRACTIONS
      IDAT=IFIX(DAT)
C NOW HAVE INTEGER DATA - ALL DATA IS IN INTEGER FORM FOR STORING
C IT INTO ANALZ FORMAT
  401 FCRMAT(10X,4(I10,5X))
C PACK INTEGER VALUES INTO ANALYZE FCRMAT
  990 FCRMAT(10X,F5.0,4I5,2R1)
      I1 = XI *(2.0**8.0)
      I2 = XJ *(2.0**8.0)
      IBUF = SBYT(1,16,IBUF,I2)
      IBUF = SBYT(17,16,IBUF,I1)
      IBUF = SBYT(43,18,IBUF,IDAT)
      PRINT 991, IBUF
  991 FORMAT(10X,O20)
      DATA(IX) = IBUF
      IX = IX +1
      RETURN
      END
```

APPENDIX A (CON'T)

```
      SUBROUTINE INTER (X2,X1,Y2,Y1,VAL,DXX)
C
C     INTERPOLATION SUBROUTINE
C
      DIFX=X2-X1
      DIFY=Y2-Y1
      XM = DIFX/DIFY
      DX = DXX - Y1
      VAL=XM*DX
      VAL = X1 + VAL
      IF(DXX.EQ.22.0) GO TO 100
      VAL = ((Y1-26.0)/2.0) * (VAL-X1)
  100 RETURN
      END
```

APPENDIX B

NAVAL POSTGRADUATE SCHOOL
DEPARTMENTS OF OCEANOGRAPHY AND METEOROLOGY

2 May 1972

Project OSTroC Ocean Sampling Program Philippine Sea

(1) Background. OSTroC (the Oceans and Severe Tropical Cyclones) is a research effort at the Naval Postgraduate School to investigate the effects of the ocean on severe tropical cyclones (typhoons, hurricanes, etc.), and conversely, the effects of the cyclones on the underlying ocean. Enough is now known about these effects to indicate that they would exert a marked influence on military operations for the areas involved. Attempts will be made to develop predictive indices for use in operational/tactical planning.

The basic difficulty in conducting studies such as OSTroC is lack of observations to sufficiently describe on a synoptic basis the oceanic changes which occur.

(2) Purpose. To establish a reasonable sampling program to determine "before" and "after" ocean thermal structure profiles in oceanic regimes susceptible to passage of severe tropical (atmospheric) disturbances.

(3) Program of Observations.

a) Regular area coverage. The initial thermal structure is needed on a regular monthly basis in the season when typhoons are likely. In the Philippine Sea

most of them occur between June and December. In these months one coverage of the total area is desired each month. If feasible, the full coverage for a given month should be made within a selected ten day period in that month. If this cannot be done, full coverage should be completed as best it can. As shown on the attached map, observations for these regular monthly coverages are desired on a 3 degree grid from 5° N to 20° N latitude and from 123° E to 144° E longitude. It is expected that the observational plan will be modified as experience is gained.

Alternate: If operational patterns are such that some other observational scheme of equivalent coverage would be easier to accomplish, a suitable change would be acceptable. It is desirable, however, that whatever the pattern of observation is chosen should be repeated monthly at nearly identical locations.

b) Coverage associated with particular typhoons. When a typhoon is approaching or is in the area, special observations are desired. If the typhoon is moving along a predictable path one or more lines of BT observations perpendicular to the predicted path of the storm are desired. These lines should be approximately 400 miles long with BTs at 25 mile intervals. The purpose of these lines is to give better and more timely data on pre-storm ocean conditions.

Immediately after the passage of the storm all lines of observations made before the storm should be repeated but BTs should be closer spaced near the storm path — at 15 mile intervals within 50 miles of the path and 25 mile intervals outside that along the 400 mile line. Additional observations should be made after the storm at any of the regular monthly monitoring positions (see attached map) which came under the influence of the storm. Also, additional lines of observations perpendicular to the storm path may be desirable to more fully describe the changes in thermal structure caused by the typhoon.

If feasible the before and after lines should be repeated at weekly intervals after storm passage for several weeks.

(4) Submission of data.

a) Via Naval Environmental Data Network (NEDN) to FNWC, then to NPS.

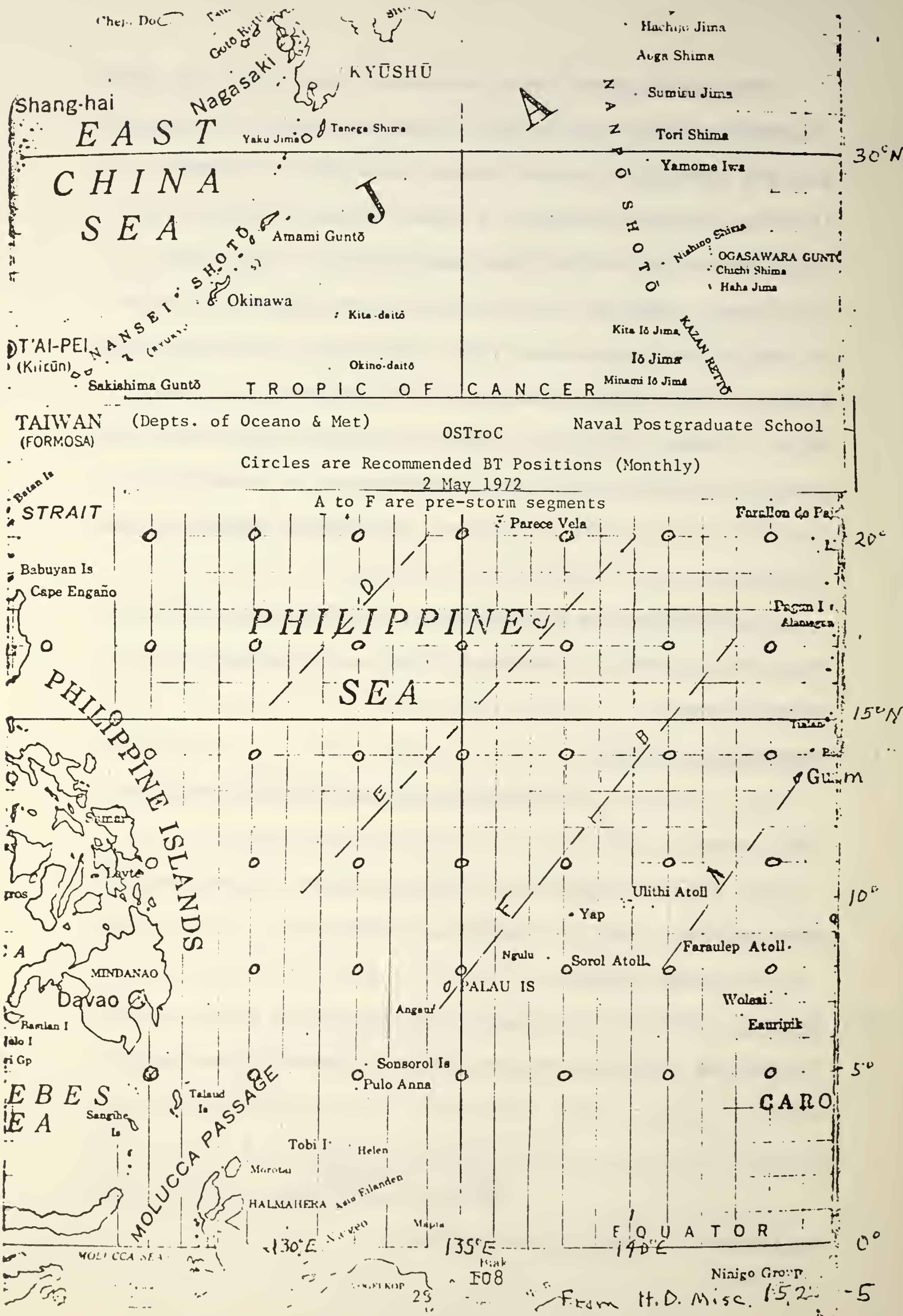
b) Mail to Supervisor Project OSTroC, Department of Oceanography, Naval Postgraduate School.

c) Naval Message.

(5) Sponsor. OSTroC is sponsored by the Ocean Science and Technology Division of the Office of Naval Research.

DALE F. LEIPPER
Project Supervisor

Enclosure I: Philippine Sea Map


EAST CHINA SEA
KYŪSHŪ
Nagasaki
Shang-hai
Yaku Jima
Tanega Shima
Hachijo Jima
Auga Shima
Sumisu Jima
Tori Shima
Yamome Iwa
NANPŌ SHOTŌ
30°N
Amami Guntō
NANSEI SHOTŌ
Okinawa
Kita-daitō
Okino-daitō
T'AI-PEI
(Kiicūn)
Sakishima Guntō
Nishino Shima
OGASAWARA GUNTŌ
Chichi Shima
Haha Jima
Kita Iō Jima
Iō Jima
Minami Iō Jima
KAZAN RETTŌ
TROPIC OF CANCER
TAIWAN
(FORMOSA)
(Depts. of Oceano & Met)
OSTroC
Naval Postgraduate School
Circles are Recommended BT Positions (Monthly)
2 May 1972
A to F are pre-storm segments
STRAIT
Parece Vela
Farallon de Pajaros
20°
Babuyan Is
Cape Engaño
PHILIPPINE SEA
Pagan I
Alamagan
15°N
PHILIPPINE ISLANDS
Samar
Leyte
MINDANAO
Davao
Guam
Ulithi Atoll
10°
Yap
Ngulu
Sorol Atoll
Faraulep Atoll
PALAU IS
Angaur
Wolesi
Eauripik
Sonsorol Is
Pulo Anna
5°
CARO
Talaud Is
Sangihe Is
MOLUCCA PASSAGE
Tobi I
Helen
Morotai
HALMAHERA
Mapia
EQUATOR
0°
130°E
135°E
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HHP
Hurricane Heat Potential
Philippine Sea
Gulf of Mexico

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The 1973 summer growth of hurricane heat potential (HHP) and its relation to tropical cyclones was studied in the Philippine Sea and the Gulf of Mexico on a monthly basis. BT information was processed through the Fleet Numerical Weather Central CDC 6500 computer to output maps of HHP, which were hand contoured. Inadequate data coverage and questionable BT observations resulted in monthly maps of varying validity and

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(20. ABSTRACT continued)

areal extent.

HHP values peaked near 35,000 cal/cm^2-column in the Gulf of Mexico and 40,000 cal/cm^2-column in the Philippine Sea in the months of August and September, the months of highest tropical storm activity.

In the Gulf of Mexico the 1973 HHP maximum-minimum values compared well with the HHP values obtained in August 1965-1968 by Leipper and Volgenau [1972].

HHP values from the Philippine Sea were in close agreement with the atlas values computed by Heffernan [1972]. Maximum values for 1973 were slightly (5000 cal/cm^2) higher.

Some evidence was found correlating rises in HHP with increases in typhoon maximum wind speed.

151297
Thesis
S4917 Shuman
c.1 1973 variations of hurricane heat potential in the Philippine Sea and the Gulf of Mexico.